AD 682517

AN ANALYSIS OF CRUISE STRATEGIES AND COSTS FOR DEPLOYMENT OF NATIONAL DATA BUOY SYSTEMS

by

Gaylord M. Northrop

November 1968

TRC Report [illegible]
Prepared for the U.S. Coast Guard
Under Contract No. [illegible]

E. J. Aubert
G. M. Northrop
Principal Investigators

THE TRAVELERS RESEARCH CENTER, INC.
250 CONSTITUTION PLAZA, HARTFORD, CONN. 06103

190

AN ANALYSIS OF CRUISE STRATEGIES AND COSTS FOR DEPLOYMENT OF NATIONAL DATA BUOY SYSTEMS

by

Gaylord M. Northrop

E. J. Aubert
G. M. Northrop
Principal Investigators

TRC Report 7493-337
Prepared for the U.S. Coast Guard
Under Contract No. DOT-CG-82504-A

THE TRAVELERS RESEARCH CENTER, INC.
250 Constitution Plaza Hartford, Connecticut 06103

This study was conducted in support of the U.S. Coast Guard National Data Buoy Systems Designated Project Officer under Contract DOT-CG-82504-A.

Views or conclusions contained in this study report should not be interpreted as offical opinion or policy of the Federal Government.

SUMMARY

The details of traveling from port to data buoy locations for data buoy system deployment and/or maintenance provide a basis for determining a large fraction of the annual operating cost of a data buoy system. Such details are also at the core of a series of highly interrelated and important questions such as, "How many buoys should a buoy-tending ship be designed to carry? What is the optimum average cruise speed? How many deployment/maintenance ports should be used? What number of days in port should follow each cruise?" Answers to all of these questions and others of similar nature are needed to provide a firm basis for U.S. Coast Guard National Data Buoy Systems development planning. This study includes investigation of each of the questions noted, and many others. The results of the investigations are presented as functions of many different parameters, including number of buoys in the system, ship buoy-carrying capacity, ship average speed, number of deployment ports, number of days in port per cruise, time-to-plant each buoy, ship operating base cost per sea day, ship maintenance cost per day, fuel cost per n mi, and others.

In this study, all system investigations have been carried out in the following manner. First, analyses were performed for each of 9 non-overlapping geographical regions called Modular Deployment Zones (MDZs) covering the oceans of the northern hemisphere. Second, certain MDZ results were combined for 6 MDZs collectively referred to as the Coastal North America (CNA) region covering the waters from the North American coast to 400 n mi off shore. Third, the results for the remaining 3 MDZs were combined for a region (outside CNA) collectively known as the northern hemisphere Deep Ocean (DO) region. Finally, results from all 9 MDZs have been combined to give averages for each of the seven specific data buoy systems considered, ranging in size from the 500-buoy baseline system down to a 60-buoy system.

To make this multi-dimensional study possible, TRC developed and programmed for the computer a buoy deployment/maintenance simulation and cost model. The model accepts as inputs the geographical locations of data buoys and ports, costs, ranges of parameters to be investigated, ocean depth for each buoy location, and sequential schedules for deployment or maintenance of buoys. The simulation model computes the distance traveled for each cruise using the great circle distance between

points; it then generates cruise time as a function of speed and time-to-plant each buoy under both ideal conditions (safety factor of 1.0) and under the assumption that a safety factor such as 4/3 is needed to make allowance for bad weather and other uncertainties. In addition to computing distance, time, and costs associated with deployment/maintenance cruises, the model also accepts buoy hardware costs—both fixed and depth dependent, such as mooring line cost—and computes the individual and cumulative costs of all buoys deployed. Average values are calculated for distance traveled per buoy planted, ship operating cost per buoy planted, mooring depth per buoy, hardware cost per buoy, deployment time per buoy, buoys deployed per ship-year, etc.

The TRC buoy deployment/maintenance model has been structured to facilitate modifications and additions. In its present state the model is applicable to a comparable study of air-droppable data buoy systems, or for a study of the use of aircraft or ships-of-opportunity to obtain marine data, etc.

The results of studies such as this are recognized to be only as good as

- The model programmed,
- The ranges and values of parameters used,
- Values of system constants used.

The basic structures of the time-to-deploy and cost-to-deploy models are simple and straightforward and are believed to be acceptably close to real-world conditions. Best strategies for deployment cruise scheduling is a relatively complex question for which there is no exact general solution, although for any given set of port and buoy locations, there is always one set of deployment cruise schedules that is at least as good or better than any other set out of the total of all possible schedules. Because the variables in this problem include (1) ship buoy-carrying capacity, (2) number and locations of buoys in a given geographical region, and (3) port locations, it was elected not to attempt to optimize deployment cruise schedules, but to use schedule strategies that could at least be shown explicitly in specific instances to be better than other strategies that appear intuitively to be as good or better. Several such scheduling strategies have been investigated and those shown to be best were used where applicable in this study. Thus, although the deployment cruise schedules used herein are not suggested as optimum, it is considered that the schedules are probably very close to optimum. The

ranges and values of parameters used in this study were specified by the U.S. Coast Guard National Data Buoy Systems Designated Project Office (USCG NDBS DPO). Most of the study results summarized below are greatly dependent on the accuracy of the parameter values and are confined to the parameter ranges specified by the NDBS DPO.

One of the most significant results to emerge from this study applies to the buoy deployment/maintenance ship. For the cost values supplied and the range of parameters investigated, the 12-buoy, 18 kt ship was clearly superior, based on average ship operating cost per buoy planted. This conclusion has been shown to be independent of selected variations in ship operating base cost per sea-day, time-to-plant each buoy, number of deployment ports, relative proximity of buoy networks to deployment port, and incorporation of prorated ship construction costs. The alternatives on either side of the 12-buoy, 18 kt ship (costing $16.4 million) are the 8-buoy, 15 kt ship (costing $11.6 million) and the 12-buoy, 21 kt ship (costing $20.8 million). Choice of the 12-buoy, 18 kt ship shows typical savings in average ship operating cost per buoy planted to be of the order of 15-17% when compared with the 8-buoy, 15 kt ship, and of the order of 6-10% when compared with the 12-buoy, 21 kt ship. Comparison with the other ships considered* shows even higher savings. As noted earlier, the validity of this result depends strongly on the accuracy of the cost factors provided.

Another salient result from the same phase of the study that indicated best ship characteristics was the range of values that appeared to apply for an important planning factor, average ship operating cost per buoy planted. For the 12-buoy, 18 kt ship and a number of other "mid-range" parameter values,† the average ship operating cost per buoy planted is about $14,000 for CNA buoys, $26,000 for DO buoys, with between $18,000 and $19,000 representing the average over all buoys. These average cost values are essentially independent of number of buoys in the system for the seven buoy systems considered.

*The other ships were: 4-buoy, 15 kt at $7.9 million; 8-buoy, 18 kt at $10.7 million; 12-buoy, 24 kt at $25.6 million; 12-buoy, 27 kt at $31.5 million; and 12-buoy, 30 kt at $38 million.

†The results are for a base ship operating cost per sea-day of $5000, time-to-plant each buoy of 24 hrs, 10 port days per cruise, a [illegible] factor of 1.5 (i.e., ideal weather and other operating conditions), and deployment from 3 ports (Portsmouth, Va., San Francisco, and Honolulu).

The system development planning factor, average-ship-operating-cost-per-buoy-planted, is sensitive to variation in base ship operating cost per sea-day. For the 12-buoy, 18 kt ship (and the other conditions noted earlier), the average ship operating cost per buoy planted varies approximately $3.00 in proportion to every $1.00 change in base ship operating cost per sea-day. The variation is higher for other ship configurations.

There is also sensitivity of the average ship operating cost planning factor to variation in time-to-plant each buoy. For the 12-buoy, 18 kt vessel (and the other conditions noted earlier), the sensitivity is of the order of $230 saved per buoy planted for each hour reduction in time-to-plant.

Average ship operating cost per buoy planted is sensitive to the number of scheduled days in port per cruise undertaken. Most of the results in this report are based on 10 port days per cruise, but factors of 5 port days and 20 port days were also investigated for both 3-port and 8-port deployment configurations. For the 12-buoy, 18 kt ship and 3-port deployment, use of 5 port days, in place of 10 port days, reduces average ship operating cost per buoy planted by 12%; using 20 port days per cruise increases the average cost per buoy planted by 25%. For the 8-port deployment, comparable changes are 13.6% reduction and 27% increase, respectively. Added costs such as those commensurate with a two-crew concept ("Blue" crew and "White" crew) needed to sustain the 5 port day condition have <u>not</u> been taken into account.

Use of 8 deployment ports, rather than 3 ports, indicates for the 12-buoy, 18 kt ship (and the other conditions noted earlier) the possibility of a 6% reduction in average ship operating cost per buoy planted in the CNA region, a 7% reduction in the DO region, and a reduction of slightly more than 6% for both regions combined. In selected MDZs the saving could run as high as 16%. None of these comments takes into account the additional expense of construction or maintenance at the additional 5 ports. In an overall sense, these additional costs would reduce the degree of saving noted.

Overall ship operating cost was computed for deployment of each of the seven data buoy systems considered. When using the 12-buoy, 18 kt ship (and the other conditions noted earlier) total deployment cost ranges from $9.121 million for the 500-buoy baseline system, to $0.944 million for the 60-buoy system. Total deployment cost is essentially a linear function of number of buoys in the system. For systems of more than 125 buoys, CNA deployment cost represents about 60% of the total deployment cost,

although the number of CNA buoys represents about 70% of the total. The DO buoys are farther apart and at greater distances from deployment ports and, therefore, cost more to deploy than CNA buoys. These total deployment costs are for ideal conditions (safety factor of 1.0).

Buoy hardware costs (considered to be conservatively high) for a data buoy comparable to the ONR discus were used to illustrate the cost capabilities of the TRC buoy deployment/maintenance simulation and cost model. It was determined that the cost of hardware deployed in the 500-buoy system would be about $146 million and nearly 5 million ft of mooring line (one-point mooring, scope of 1.0) would be required. Under the assumption that oceanographic sensor packages would be mooring-mounted at up to 20 IAPSO levels through 5000 m depth, 8,336 packages would be required— an average of 16.8 sensor packages per buoy. Using the hardware costs provided, these sensor packages represent 40% of the total buoy hardware cost, and the mooring represents 6% of the cost. (The buoy hull cost would be only 27% of the total.) The buoy hardware costs cited in this report are not intended for use in financial planning.

Another useful planning factor that has emerged from this investigation is the average maximum number of buoys deployed per ship-year* For the 12-buoy 18 kt ship and 3-port deployment (and the other conditions noted earlier), this planning factor has maximum numbers of buoys planted per ship-year of 137 CNA buoys, or 90 DO buoys, or 120 buoys for the combined regions. If 8-port deployment is used, the values become 141 CNA buoys, 96 DO buoys, or 125 combined DO and CNA buoys planted per ship-year. These factors apply for a safety factor of 1.0 (ideal conditions) and probably should be degraded by 10% to 30% to account for bad weather and other operational uncertainties.

One of the minor goals of this study was to consider briefly system relative effectiveness of the seven buoy system configurations. (The buoy systems varied both in numbers and locations of buoys.) Some system relative effectiveness values have been obtained, but it is stressed that this was done more to illustrate some of the

*There were assumed to be 336 ship-days per ship-year, leaving 60 days for overhaul every 2 years.

facets of a more comprehensive study of system relative effectiveness that should be undertaken. Such a study would concentrate on relating numbers and locations of buoys to the potential economic, research, social, and military benefits that might derive from the use of the collected data and/or data products (forecasts, etc.). The minor effort undertaken for this report indicates that marginal system relative effectiveness per buoy added would be greatest for the small 60-buoy system and would decrease almost linearly as the number of data buoys in the system increases. Beyond the 375-buoy point (nearly 95% system relative effectiveness) the marginal increase for each added buoy is quite small. In part, this conclusion is due to the assumption that the 500-buoy baseline system is 100% effective. The brief attention devoted to this subject suggests that system relative effectiveness is greatly enhanced by allowing the system designer considerable freedom to select buoy locations that are closely related to satisfying data requirements that have high benefits. An alternative to this policy—building up the number of buoys with uniform emphasis in all 9 Modular Deployment Zones—is shown to be much less effective, in general.

As noted at the outset of this summary, the primary goal of this study has been the provision of analyses and results to aid the development planning for National Data Buoy Systems. It is recognized that this study is not definitive in many of the subject areas addressed, but it is believed that the study results, properly interpreted in their application, will suffice as a partial foundation for planning at this stage of development of National Data Buoy Systems. As buoy and port locations, costs, and other factors become more firmly established, the buoy deployment/maintenance simulation and cost model can be used to refine or develop as needed planning factors such as those presented in this report. As interest shifts from deployment of buoys to cyclic maintenance, the computer model can still be used. Addition of other features to the model, such as weather conditions and some decision rules relating weather and operations, can and should be undertaken. In this vein, then, this study offers an initial foundation for certain facets of NDBS development planning, and an invitation to use these results as a point of departure for further study efforts.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Figure	Title	Page
5-16	Sensitivity of Average Cost Per Buoy Planted to Variation in Base Cost Per Sea Day	78
5-17	Sensitivity of Average Cost Per Buoy Deployed to Variation in Base Cost Per Sea Day	79
5-18	Sensitivity to Time-to-Plant	81
5-19	Total Minimum Deployment Days Per Modular Deployment Zone	83
5-20	Maximum Number Buoys Deployed Per Ship-year and Minimum Average Deployment Time	84
5-21	Longest Cruise Time Per Modular Deployment Zone	85
5-22	Maximum Cruise Time for all Buoy Systems	87
5-23	Total Minimum Deployment Time for all Systems	88
5-24	Average Mooring Depth and Total Length of Mooring	90
5-25	Length of Mooring for Seven Data Buoy Systems	91
5-26	Oceanographic Sensor Packages	94
5-27	Oceanographic Sensor Packages for Seven Data Buoy Systems	96
5-28	Buoy Hardware Cost Per Modular Deployment Zone ~ Baseline System	97
5-29	Average Buoy Hardware Cost Per Modular Deployment Zone	98
5-30	Buoy Hardware Cost for Seven Data Buoy Systems	99
6-1	8-Port Configuration	101
6-2	Total Distance Traveled	103
6-3	Average Distance Traveled Per Buoy Planted	104
6-4	Total Deployment Time	105
6-5	Average Deployment Time	106
6-6	Ship Operating Deployment Cost	108
6-7	Average Ship Operating Deployment Cost Per Buoy Planted	109
6-8	Average Ship Operating Cost Per Buoy Planted	110
6-9	Reduction in Deployment Characteristics: 8-port vs 3-port	113
7-1	Time to Deploy Buoys (3-Port Deployment)	117
7-2	Average Deployment Time Per Buoy Planted (3-Port Deployment)	119
7-3	Cost to Deploy Buoys (3-Port Deployment)	120

FOREWORD

Contract Number DOT-CG-82504-A between the U. S. Coast Guard and The Travelers Research Center, Inc. (TRC) consists of five parallel activities. The five final reports stemming from these activities are entitled:

(1) Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meterological and Oceanographic Data

(2) Characteristics of National Data Buoy Systems: Their Impact on Data Use and Measurement of Natural Phenomena

(3) Cost Effectiveness Sensitivity of National Data Buoy Systems: An Essay

(4) Computer Programs for National Data Buoy Systems Simulation and Cost Models

(5) An Analysis of Cruise Strategies and Costs for Deployment of National Data Buoy Systems

Each of these five reports is complete in itself, but it must be recognized that in all instances the other four activities both influenced and contributed to the results presented in each individual report.

The present USCG/TRC contract is an outgrowth of a study of the feasibility of national data buoy systems performed by TRC and Alpine Geophysical Associates for the USCG during 1967. Need was evident for investigation, research, and analysis in greater depth in several areas to support the concept formulation and deployment planning efforts of the newly-formed U. S. Coast Guard National Data Buoy System Designated Project Office (NDBS DPO). This report and the other four cited above satisfy some of those needs.

All five TRC reports have benefited from the close cooperation and guidance afforded by the USCG NDBS DPO. Contributions have been made by Capt. J. [illegible] (Project Manager), Cmdr. V. Rinehart, J. [illegible], E. [illegible], P. Merrill, and Lt. Cmdr. W. Martin (Contract Monitor). Acknowledgment is also given to the following members of the TRC staff for significant assistance in the preparation of this report: E. L. Davis, S. J. [illegible], A. S. [illegible], and G. M. [illegible].

1.0 INTRODUCTION

As part of the 1968 TRC contractual effort for the U. S. Coast Guard National Data Buoy System Designated Project Office (NDBS DPO), TRC proposed to develop a computer automated data buoy system deployment and maintenance model. This model is described in Reference 1. For NDBS DPO technical development planning purposes, it was considered necessary to have a more sophisticated, flexible system simulation deployment and maintenance model than was used for the 1967 National Data Buoy Systems Feasibility Study. [2]

TRC also proposed as part of its 1968 effort for the NDBS DPO to use the deployment aspects of the computerized simulation model to analyze a selected number of system deployment and operations characteristics to provide inputs for NDBS DPO technical development planning for potential national data buoy systems. This report presents the results of the analysis of data generated by the buoy deployment and maintenance simulation and cost model.

1.1 Objectives

The principal objective of this study is to develop cost information related to the physical deployment of data buoys at specified locations throughout the northern hemisphere Deep Oceans and the Coastal North American Region extending 400 nautical miles (n mi) from shore.

A number of corollary objectives are also met in the course of satisfying the principal objectives. These are:

- Determination of deployment ship buoy-implanting capability per unit time for each of 9 identified geographical regions.
- Delineation of sensitivity of costs to variations in:
  - base ship cost per day of operation at sea
  - time required to plant each buoy
  - number of days to be spent in port following each cruise
  - choice of deployment port location.
- Determination of data buoy hardware costs as a function of geographical region and location.

1.2 Limitations

As is often the case with studies of this type, a number of limitations must be imposed on the use of the results. Primary among these is the need to recognize that ship operating costs for deploying buoys as presented herein represent the minimum attainable costs, because effects of seasonal climate changes and daily weather conditions have not been considered. Also, the possible inability of the deployment ship to carry out buoy implanting during night hours has not been expressly taken into account, although the range of time-to-implant investigated should be adequate to cover all interesting possibilities. These limitations on the use of the results of this study are considered to be minor at this stage of technical development planning, because a broad scope of conditions has been investigated and the limitations noted can be easily circumvented by reasonable interpretation of the data and the results of the analysis.

Since many of the results of this study are presented in the form of costs, it is obvious that one potential limitation on the use of the results hinges on the degree of accuracy associated with the cost input data. Cost data were provided by the NDBS DPO for basic ship cost per day, fuel cost per n mi as a function of both ship buoy-carrying capacity and speed, and maintenance cost per day pertaining to ship components (also a function of ship buoy-carrying capacity and speed). In addition, construction costs were given for ships of various buoy-carrying capacities (4, 6, 8, 10, and 12) and speeds (9, 12, 15, 18, 21, 24, 27, and 30 kt). In general, the ship maintenance costs provided tend to be constant as a function of speed in the range of 9 to 15 kt, but they vary over a range of $250 to $600 per day as a function of buoy-carrying capacity. As speeds increase to values above 15 kt, ship maintenance cost rises to $1400 per day at 30 kt for all buoy-carrying capacities considered. Fuel costs have similar characteristics ranging between $2 to $6 per n mi at low speeds and for varying capacities; fuel cost rises to $30 per n mi at 30 kt for all buoy-carrying capacities. Ship construction costs range from approximately $9 million for a ship with a 4 buoy-carrying capacity in the low speed range, to $39 million for a 30 kt ship regardless of buoy-carrying capacity in the range considered (4 to 12 buoys). In addition to the maintenance and fuel costs, a range for base cost per sea-day of $2000 to $8000 was established by the NDBS DPO. System cost data were to be calculated by the model at these two values and at an intermediate value of $5000. These costs are considered representative of a

number of various shipborne personnel configurations covering a variety of seaborne operational deployment and maintenance concepts.

It was considered desirable by the NDBS DPO to establish a measure of system effectiveness provided by each of the seven buoy system configurations outlined below. The NDBS DPO recognized that at this stage of deployment effort, only a subjective analysis of this question could be undertaken by TRC. Before a thorough study of this subject can take place, it will be necessary for the government agencies stating data requirements to undertake a comparative evaluation of the relative value of marine invironmental data as a function both of parameters measured and geographical area from which the data are collected.* Other important facets of this problem include location of sensors in the vertical and reporting time schedules, as well as instrumentation accuracy, range, etc. The data products to be prepared and the benefits derived from the ultimate use of the data products are also important ingredients in determining system effectiveness. Until relative values of data and benefits have been determined by the required agencies, it is not possible to carry out a truly objective analysis of system effectiveness. It is hoped that the subjective results described here may be of some use in generating the data base required for future objective system effectiveness analyses.

In this study, the output of the buoy deployment model is many-fold. It provides:

- The approximate cost of all buoys deployed, individually by location in one of the nine regions, and in total
- The total length of mooring line required, as above
- The total number of mooring-mounted underwater oceanographic sensor packages, as above
- The total distance traveled for each cruise and the total distance traveled for the entire deployment, by geographical regions and in total
- The average hardware cost per buoy planted, as above
- The average cost ascribable to ship operations required to plant each buoy, as above

---

*An effort to collect relative values from agencies has been undertaken by the NDBS DPO. The results are reported in final reports for other areas of endeavor of the 1968 USCG/TRC contract [3, 4], but they were not made available in time for use in this study.

- The minimum number of sea-days required for each cruise
- The total number of sea-days required for an entire deployment, by geographical regions and in total
- The number of port-days per cruise
- The total number of port-days for an entire deployment, by geographical regions and in total
- The total ship cost (sea-days plus port-days) for an entire deployment, both as a minimum value and with a 4/3 safety factor applied
- The sensitivity of system costs to variation in base cost per sea-day ($2000, $5000, $8000/day)
- The sensitivity of system costs to variation in time-to-implant each buoy (12, 24, 30, 36 hours)
- The costs of implanting buoys as a function of ship speed (9 to 30 kt in increments of 3 kt) and ship buoy-carrying capacity (4, 6, 8, 10, 12 buoys)
- The average distance traveled per buoy planted in each of the nine geographical areas
- The average number of days required to plant each buoy, as above
- The average number of buoys planted in a 335 day working year

Typical examples of the buoy deployment and maintenance simulation and cost computer model output are shown in Appendix A. The usefulness of the computer model employed in this buoy deployment study extends beyond the applications described here. For example, the model has been designed to accommodate scheduled maintenance of buoys, in which the number of buoys visited exceeds the number carried and, hence, on-board refurbishment of data buoys is required.* The model can accommodate the concept of leaving a port, visiting a depot to take on buoys, deploying (or maintaining) buoys and then returning to a different depot and/or port. The model can be instructed to test the ability to go to each successive buoy location and return to port within a specified total number of cruise days. This feature is especially useful for testing the feasibility of minimizing the number of maintenance cruises by use of an on-board refurbishment concept. It is anticipated that the buoy deployment and maintenance computer model will be of use to the NDBS DPO throughout the foreseeable future.

*In this report, refurbishment implies both replacement of components and minor repairs of non-replaceable items, such as the buoy hull.

1.3 Approach

The approach undertaken in this study has been developed in close conjunction with U. S. Coast Guard NDBS DPO. For example, the NDBS DPO selected Portsmouth, Va., San Francisco, Calif., and Honolulu, Ha., as deployment ports. With NDBS DPO guidance it was decided that the baseline NDBS system for the study would consist of 500 data buoys in the northern hemisphere, with 150 Deep Ocean (DO) buoys spaced approximately 500 n mi apart and 350 Coastal North American (CNA) buoys spaced approximately 100 n mi apart in a region around the North American Continent out to 400 n mi from shore. These spacings are considered representative of fineness of grid sufficient to satisfy a majority of the identified operational data requirements in these regions.*

Six additional buoy network configurations were also selected for this study. They include a three-fourths baseline system (375 buoys), two 50 percent base line configurations (250 buoys each), two 25 percent base configurations (each 125 buoys) and a 12 percent baseline configuration (60 buoys).

The rationales for locating data buoys in the DO and CNA regions were determined in gross fashion in conjunction with the NDBS DPO; details of actual choice of latitudes and longitudes were left in the hands of TRC. In general, the approach used for choosing buoy locations was as follows: Meeting grid spacing requirements of 500 and 100 n mi dictated the locations of most of the buoys in the baseline system; location of the 375 buoys in the three-fourths baseline system was based on a 600 n mi DO grid and a variable 100-150 n mi CNA grid developed as part of the 1968 refinement of marine environmental data requirements carried on at TRC in parallel with this study [S]. Many of the 375 buoys are located to meet specific operational requirements stated by U. S. government agencies. The grid spacings for the 375-buoy system have been accepted by agency representatives as reasonable for an initial

*In an actual deployment, the positioning of buoys will be a function of many variables and inputs. For the purposes of this study, it is considered sufficient to deal with representative numbers of buoys at representative spacings in the geographical regions of interest. The number of buoys involved is sufficiently large to give a good statistical sample, as can be seen from the results discussed in the remainder of this report.

NDBS in the DO and CNA regions. (The agencies have not approved the locations used in the 375-buoy networks.) Locations for the one-half baseline system fell into two categories. In one category the locations of the 250 buoys were left to the discretion of the "system designer" and tended to be specified at those 250 locations of the 375-buoy system subjectively deemed most beneficial to data users. In the second category the "system designer" was constrained to locate buoys in each of the 9 geographical regions in the northern hemisphere; the number of buoys for each region was constrained to be 50 percent of the number of baseline buoys originally resulting from the desired grid spacing in that region. These same rationales were used in choosing locations for each of the one-fourth baseline systems (there are two). Buoy locations for the 12 percent of baseline system were left to the discretion of the "system designer."

In all cases left to the discretion of the "system designer," there was a general understanding between TRC and the NDBS DPO that in the event there were small numbers of buoys deployed in a given region, the locations would tend to concentrate more or less in the vicinity of the deployment ports and that no isolated, special purpose buoys at great distances from port would be included. The NDBS DPO specified that the study should consider ships with buoy-carrying capacities of 4, 6, 8, 10, and 12 data buoys. The exact deployment cruise schedules from port to buoy locations and back to port were selected by TRC. While it is clear that each cruise is a form of the classical Traveling Salesman Problem (for which there is no general solution), the nature of the buoy locations - most being essentially at points in a grid rather than randomly distributed throughout a given area - is such that rather clear-cut preferable strategies for ship deployment of buoys become quickly evident. Substantiating details for this statement are given in Appendix B.

2.0 CONCLUSIONS

The following conclusions drawn from this study must be weighed by the reader with due consideration to the limitations of the buoy deployment model and the recognition that representative cost data and representative buoy locations have been used throughout the study (see Section 1.2).

2.1 Ship Characteristics

All aspects of this study make evident that the optimum average ship speed for deployment of Deep Ocean and Coastal North American buoys lies in the range of 15 to 18 kt. The average cost per buoy planted is monotonically decreasing as a function of increasing ship buoy-carrying capacities, throughout the ship buoy-carrying capacity investigated. Loosely speaking there is a two-to-one reduction in average cost per buoy planted between the 4-buoy ship and the 12-buoy ship, at all speeds. About two-thirds of this improvement is achieved in going from a 4-buoy to an 8-buoy ship. For an average time-to-plant each buoy of 24 hours, there does not appear to be a strong reason for considering buoy-carrying capacities in excess of 12, as long as 22.5 days represents a desired cruise time for ideal operating conditions*. Thus, the 8-buoy, 15 kt ship at a construction cost of $11.6 million represents what might appear to be a "best" choice, but provides little system flexibility. The $16.4 million ship, capable of operating at average speeds of 18 kt and carrying 12 buoys, represents a more expensive choice in terms of ship construction, but it is a choice that provides all the flexibility that appears necessary for both deployment and later buoy maintenance.

2.2 Deployment Ship Cruise Strategies

Schedules for ship operation from port-to-buoy locations and back to port are generally "best" when approximately half the buoys are deployed on the trip out to the farthest buoy visited and the other half are deployed on the return, and the deployment covers a roughly rectangular "block" of buoys. If buoys were located according to

*This implies a safety factor of 1.0. If a safety factor of 4/3 is used, the desired maximum cruise time becomes 30 days, of which 7.5 days is allotted to delays caused by bad weather, etc. The concept of a desired maximum cruise time of 30 days, of which approximately 22.5 days is actually spent in transit and planting buoys, was designated for the study by the NDBS DPO.

certain geometrical patterns, it would be possible to quickly arrive at the best possible deployment cruise schedules. In actual application, buoys tend to deviate somewhat from precisely consistent geometrical patterns, and mixed strategies (see Appendix B) appear to be best.

2.3 Buoy Deployment Ship Cruise Times and Distances

As would be expected, the time duration of deployment cruises increases as a function of buoys deployed. Using the ports of Portsmouth, Virginia, and San Francisco, California, to deploy buoys in the Coastal North American regions, a buoy-carrying capacity of 12 is acceptable even in the case where buoys are deployed to regions at a considerable distance from the ports. Throughout much of the CNA region, reductions in time-at-sea can be achieved, if the deployment ship operates from a port contiguous to the geographic area within which deployment is taking place, rather than from a port at some distance from the geographic area. In the northern hemisphere Deep Ocean areas, when deploying from Portsmouth, Virginia, and Honolulu, Hawaii, some deployments may have to be considered "hardship cruises,"* if deployment of more than 4 buoys is contemplated.

The actual distance and time of cruise in each of the 9 geographic areas in the northern hemisphere is only partially dependent on the number of buoys carried. It is essentially a function of visiting the buoy location at the farthest distance from the deployment port. In the CNA regions the cruise of greatest distance can be held to approximately 1800 to 2500 n mi for ports contiguous to the deployment zone. If buoys must be taken from a port to an adjacent deployment zone, the longest cruises are in the range of 4000 to 5000 n mi. In the Deep Ocean the longest cruises tend to be approximately 10,000 n mi in length when the port is contiguous with the deployment zone. Cruises of 16,000 n mi in length have been encountered in this study in deploying DO buoys from a port in one DO zone to an adjacent zone (i.e., buoys deployed in the northwest Pacific from Honolulu).

2.4 Cost of Buoy Deployment Cruises

Based on the assumptions of 18 kt average speed, one day time-to-plant, $5,000 base cost per sea-day, and a safety factor of 1.0, this study shows that the average cost

*That is, minimum possible cruise time for some cruises will exceed 22.5 days.

of cruises for a 12-buoy ship in the Coastal North American regions will lie in the $150,000 to $200,000 range. In the Deep Ocean regions, for comparable conditions, average cruise cost is slightly less than $300,000. If prorated ship construction costs are to be added to these figures, they would be based on $820,000 per year ($2250 per day) for the $16.4 million ship.* A 22.5-day cruise followed by 10 days in port would involve $73,000 of prorated ship costs. Average cruise costs are commensurately lower for ships carrying fewer buoys, since average cruise distance travelled to deploy all buoys is greater.

2.5 Average Ship Operating Cost per Buoy Planted

In addition to average cruise cost, another convenient planning factor is the average ship operating cost per buoy planted. This planning factor is a function of distance travelled, time to plant each buoy, port days per cruise, ship speed, ship buoy-carrying capacity, base cost per sea-day and ship maintenance and fuel costs. For this study the average ship operating cost per buoy planted has been computed on the basis of buoys deployed first in limited geographical areas, then in broader regions, and finally over the entire northern hemisphere.

The analysis has established that average ship operating cost per buoy planted is approximately $15,500 per buoy for buoys deployed within 400 n mi of coastal North America; it is about $26,000 per buoy for buoys deployed in the northern hemisphere Deep Ocean regions outside the Coastal North America region; and it is about $19,000 per buoy when both the Deep Ocean and Coastal North America regions are combined. These values are essentially independent of the number of buoys deployed for the range investigated (60 to 500 buoys). The basis for these average costs is as follows: Base cost per sea-day of $5,000, 24 hr time-to-plant, ship speed of 18 kt, ship buoy-carrying capacity of 12, a safety factor of 1.0, and 10 port days per cruise.

2.6 Cost of Deployed Data Buoy Hardware

Using the cost figures provided by the NDBS DPO for a typical large discus buoy, and an operational maintenance cycle of approximately one year, illustrative deployed buoy hardware costs have been computed to give cost comparisons for initial deployments. In general, these costs are linearly dependent on the number of buoys deployed

---

*Prorated on the basis of 20 years (7300 days).

and total length of mooring required for all buoys. The costs are slightly non-linearly dependent on mooring depth, because in the upper ocean layer oceanographic sensor packages are assumed mounted on the mooring as a non-linear function of depth. In round numbers, an average cost for a Coastal North American buoy would be approximately $280,000· a Deep Ocean buoy would cost $310,000. The overall average hardware cost for all deployed buoys is approximately $290,000/buoy.

2.7 Relationship of Deployment Cruise Costs to Buoy Maintenance Cruise Costs

The results developed in the course of this study are adequate for gross determination of maintenance cruise costs, even in those instances where the number of buoys maintained exceeds the number of buoys carried from port (i.e., on-board buoy refurbishment takes place). In general, buoy deployment costs—typically of the order of $9 million (minimum)* for the baseline 500-buoy system—represent an upper bound on expected periodic maintenance costs, once buoys are deployed.

By tending more buoys per cruise than a ship can carry, the efficacy of the cruise is improved and ship operating costs for maintenance would be less than those developed herein for deployment only, where the number of buoy locations visited is always identical to the number of buoys carried from port.

A description of a possible situation amenable to use of the deployment/maintenance simulation and cost model is given in the following scenario. The maintenance ship, with eight ready-to-deploy buoys aboard, leaves port in time to arrive at the first buoy to be maintained at 0300. Once on station, the maintenance ship deploys a buoy, checks out operation of all equipment, and removes the buoy that has just been relieved. All of these operations are completed within 15 hours after arrival on station. By 1800 to 2100, the maintenance ship is ready to depart for the next buoy to be replaced, about 100 to 150 n mi away. At an average cruise speed of 18 kt, the maintenance ship will arrive on site at approximately 0300 the following morning.

While these day-long operations—deploy a buoy and retrieve a buoy, then journey to the next buoy—are being performed, the first buoy retrieved is being refurbished and

*This value is based on 500 buoys deployed, $5000 base cost/sea-day, 24 hr time-to-plant-each-buoy, 10 port days/cruise, 12 buoys deployed each cruise, and a safety factor of 1.0. If a safety factor of 4/3 is used, buoy deployment cost would rise to about $12 million, for the same set of stipulated conditions.

checked out aboard ship. At the rate of one buoy replaced per day, a maximum of eight days is available (though not necessarily needed) to carry out on-board refurbishment. Thus, the ninth and successive buoys maintained are replaced by buoys refurbished on board during the cruise. Following a procedure such as this, it might be possible to depart port, maintain up to 20 buoys, and return to port within a period of about 22.5 days. Of course, the buoys would have to be spaced relatively closely (100—150 n mi) to keep cruising time to about 5—8 hr during the middle of each night. Also, to fit this scenario, the port of departure and return must be contiguous with the region in which the buoys are deployed.

When the buoys are about 600 n mi apart, the travel time between buoys becomes of the order of 33 hr (at 18 kt), and at least two days would be required for each deployment, retrieval, and journey to the next site. Also, it is likely that an average of at least three days in total would have to be allocated to the port departure and port return portions of the cruise. Thus, within 22.5 days, at most only 10 buoy stations would be visited. If the duration of the cruise is extended to 29 days, then 16 buoy stations would be visited.*

Even if a 12-buoy ship visits only 9 or 10 Deep Ocean buoy locations to perform maintenance, on-board refurbishment of buoys may take place. For example, if eight days is required for on-board refurbishment, then only four buoys would need to be carried for Deep Ocean cruises (carrying five would allow for a margin of safety). It is desirable to carry a minimum number of buoys, because the buoys on board represent capital investment not in use, and in a system such as this, the investment in spares (unused capital) should be held down to a prudent level commensurate with the uncertainties attending the maintenance operation.

The present buoy deployment/maintenance simulation and cost model is capable of handling the explicit details of the typical scenario outlined above, thus permitting the testing of hypothetical maintenance schedules and the determination of scheduling feasibility and costs.

---

*All of this discussion is based upon the concept that a cruise planned for 22.5 days can be extended to as much as 30 days, in the event of bad weather, etc., thus implying a scheduling safety factor of 1.33. Planning the cruise to last 29 days, however, implies that a safety factor of approximately 1.0 has been used, and in the event of any mishap, the actual cruise might last longer than 30 days. It might then be classed as a "hardship" cruise. Of course, that does not mean it could (or would) not be undertaken.

2.8 Choices of Deployment Ports

The special attention directed in this study to comparing deployment costs from three ports and eight ports indicates that initial deployment savings of up to $0.24 million to $1.8 million might be achieved by using eight ports. The conditions for which these savings may be possible are shown in Table 2-1. Such savings are based on data for the 375-buoy network, extrapolated to the 500-buoy and 250-buoy cases. Less savings would be encountered for smaller buoy networks because the distance from port to the farthest buoy was consistently reduced as the total number of buoys in the system was reduced. For example, most of the buoys in the 12 per cent of baseline system (60 buoys) were located in the geographic zones contiguous to the two deployment ports used. Essentially none of the 60 buoys was located in the Deep Ocean regions.

TABLE 2-1
POTENTIAL DEPLOYMENT SAVINGS ($M)*: 8 PORTS VS 3 PORTS

No. buoys	Ship buoy-carrying capacity		
	4	8	12
500	1.79	0.89	0.48
375	1.34	0.67	0.36
250	0.90	0.44	0.24

*Notes: (1) Time-to-plant = 24 hr
(2) Base Cost/sea-day = $5000
(3) Port days/cruise = 10
(4) Safety factor = 1.0

Use of Table 2-1 must be tempered by recognition that additional costs have not been included for port facilities, crew on-shore facilities, transportation of buoys to the ports prior to deployment (possibly carried out by a very large commercial or naval vessel capable of handling at least 30 buoys per trip).* Costs such as these would reduce the potential savings shown in Table 2-1. Also, once buoys are deployed,

*Crew morale, an intangible factor, is sometimes adversely effected by returning to a port other than the home port.

a maintenance scheme permitting refurbishment on board would make maintenance cruises more efficient than deployment cruises, thus further reducing the potential for savings due to increased numbers of ports. In general, on a Modular Deployment Zone (MDZ) basis,* greatest savings appear possible in the North Pacific West MDZ. Smaller, but substantial, savings would be accrued by use of a port at San Diego (rather than San Francisco) to deploy buoys in the Mexican Coast MDZ. For the Gulf of Alaska MDZ, potential savings of $2000 per buoy planted might be achieved by deploying buoys from Ketchikan, Alaska, rather than from San Francisco. At first estimate, this saving must be viewed as marginal, since other costs could easily approach the $88,000 that might be saved.**

Use of U.S. eastern seaboard ports other than Portsmouth, Virginia, provides potential savings of about $1000 (or less) per buoy planted in the Grand Banks and Gulf of Mexico MDZs. Such savings cannot be viewed as highly significant, because they would doubtless be reduced by costs that have not been included in this analysis.

2.9 Effect of Variation in Time-In-Port Per Cruise

A factor of 10 port days per cruise has been used throughout most of this report; in Section 7.0 the effect of using values of 5 and 20 port days per cruise has also been considered for the 375-buoy system, deployed from both the 3-port and 8-port configurations. Table 2-2 shows a summary of the results for the 12-buoy, 18 kt ship, with safety factor of 1.0, and time-to-plant of 24 hrs. The data from Table 2-2 indicates that reducing port time per cruise from 10 to 5 days reduces total deployment time by about 16% for both 3-port and 8-port deployments. Increasing port time per cruise from 10 to 20 days increases deployment time by 30% in both cases. Similar changes around 10 port days per cruise result in variations in total deployment cost of about 13% reduction for 5 port days per cruise and 26% increase for 20 port days per cruise.

A reduction of one port day per cruise from a nominal value of 10 has an overall average effect of increasing the deployment capability of the 12-buoy, 18 kt ship by

*For a description of Modular Deployment Zones, see Section 4.1.

**In the 375-buoy system there are 44 buoys in the Gulf of Alaska MDZ; hence, savings of up to $88,000 might be achieved for the stipulated conditions in Table 2-1.

about 4 to 5 additional buoys per ship-year, although consideration of specific geographical regions and ports might modify this planning factor by as much as a factor of 2.0.

TABLE 2-2
SENSITIVITY OF DEPLOYMENT CHARACTERISTICS
TO VARIATION IN PORT DAYS PER CRUISE

Port days per cruise (days)	Total deployment time (ship days)	Total deployment cost ($M)	Average cost per buoy planted ($K)	Average no. buoys planted per ship-year
3-port				
5	885	5.95	15.9	142
10	1,045	6.8	18.1	120
20	1,363	8.46	22.6	92
8-port				
5	840	5.53	14.7	150
10	1,004	6.4	17.0	125
20	1,328	8.09	21.6	95

Notes: 1. Time-to-plant = 24 hrs
2. Base cost/sea day = $5000
3. Safety factor = 1.0
4. Ship speed = 18 kt
5. Days/ship-year = 335

2.10 System Relative Effectiveness

The very brief investigation of system relative effectiveness* undertaken in this study was confined to a limited number of economic user categories (seven), that did not include military or all social (general public) users. Primarily for illustrative purposes, relative estimates of data use were subjectively made for each of the 7 economic user categories in each of the 9 MDZs for each of the seven data buoy systems. The results indicated that higher system relative effectiveness could be achieved by allowing the system designer flexibility to locate buoys where the data (or data products) give rise to greater benefits. The average marginal system relative effectiveness** decreased linearly through the 375-buoy system to a value of 0.18% per buoy. In going from the 375-buoy to the 500-buoy (baseline) system, the average system effectiveness reduced sharply to only 0.043%, indicative of the fact that the 375-buoy system (unconstrained deployment) had a relative system effectiveness of nearly 95% in comparison to the 100% effectiveness assumed for the 500-buoy baseline system. This cursory system relative effectiveness effort is intended only to provide some insight into this subject and to outline a "strawman" approach for a much needed thorough study in the future of system relative effectiveness.

* To avoid undue complication in preparing the illustrative example, it was assumed that the 500-buoy baseline system was 100% effective in satisfying the user needs. The effectiveness of the other six buoy systems was then estimated for each of the seven user categories relative to the (assumed) effectiveness of the base line system. This procedure would not have been used, if more resources had been available for this part of the study.

** Average marginal system relative effectiveness is the change in estimated relative system effectiveness divided by the number of buoys involved in the change.

3.0 COST DATA

3.1 Ship Costs

The cost of operating a ship to deploy buoys at selected locations is in large part a function of a base cost per sea-day—a cost defined in this study to be primarily determined by the number of personnel aboard ship. The USCG NDBS DPO has specified two basic ship options for this study: an automated ship requiring a minimum ship operations crew, and a conventional ship. The NDBS DPO considers at this time that a marine data-gathering team of 19 men will be used aboard data buoy tenders for collecting comparative data to assure that each implanted buoy is operating properly, and to acquire additional data enroute and at sites where data buoys would not be located. The number of personnel required in addition to the ship crew and the marine data-gathering team will depend on the buoy deployment/maintenance concept implemented. For example, buoy maintenance might be achieved by complete refurbishment at sea; then more buoys would be maintained per cruise than are carried on board from port. Or, all buoys may be refurbished at a shore depot; the number of buoys maintained each cruise would then be equal to the number of buoys carried from port. Table 3-1 delineates ship manning for the automated and conventional ship approaches. Using the conservatively high figure of $55/day as the average cost of personnel aboard ship (includes considerable overhead), it is evident that personnel costs per day lie in the range $6900 to $4270. For this study the NDBS PMO directed that an average base cost per sea-day of $5000 be used, and that values of $2000 and $8000 also be investigated to ascertain the sensitivity of results to variations in base cost per sea-day.* The NDBS DPO directed that a ship maintenance cost per sea-day that is a function of both ship speed and ship buoy-carrying capacity should be added to the base cost per sea-day. Also, the NDBS DPO provided fuel cost per n mi as a function of ship speed and buoy-carrying capacity. These data are shown in Table 3-2 along with ship construction cost commensurate with the ship maintenance and fuel cost data.

*Use of three base costs per sea-day is easily translated into other meaningful figures. For example, $5000/day is equivalent to an average cost of $48 per day ($17,5[illegible]/year) for each member of the 104-man crew aboard the maximum maintenance automated ship.

TABLE 3-1
SHIP MANNING

Ship	Ship Crew	Marine Data Gathering Team	Buoy Deployment Maintenance Crew		Total Personnel	
			Max.	Min.	Max.	Min.
Automated	45	19	40	24	104	78
Conventional	67	19	40	24	126	110

The total ship cost attributable to deploying buoys is the sum of three terms:

(1) Ship maintenance cost per sea-day plus base cost per sea-day, both multiplied by number of days at sea

(2) Ship maintenance cost per sea-day plus base cost per sea-day, both multiplied by 0.94 and in turn multiplied by the number of days in port (number of days in port per cruise was set at 10 by NDBS DPM direction),

(3) Fuel cost per n mi multiplied by total distance traveled per cruise.

These terms are shown in the following equation.

$$C = [B + M] \times \left\{ \left[\frac{D}{S \times 24} \right] + [N \times T] + [0.94 \times P] \right\} + [D \times F] \qquad \text{(Eq. 1)}$$

where C = Total Ship Cruise Cost ($)

B = Base Cost/Sea-Day ($)

M = Maintenance Cost/Sea-Day ($)

D = Distance Traveled (n mi)

S = Ship Speed (kt)

N = No. Buoys Deployed

T = Time-to-Plant Each Buoy (days)

F = Fuel Cost/n mi ($)

P = Port Time/Cruise * (days)

*Port time/cruise may be made variable with fixed upper and lower bounds, as a function of the ratio of buoys carried to ship buoy-carrying capacity. The buoy deployment maintenance model provides this convenience.

TABLE 3-2
SHIP COST DATA

Ship Maintenance Cost/Sea-Day In Dollars

Ship Speed	Ship Buoy-Carrying Capacity				
	4	6	8	10	12
9	246	306	445	600	600
12	246	306	445	600	600
15	246	306	445	600	600
18	306	306	600	600	600
21	515	780	780	780	780
24	980	980	980	980	980
27	1200	1200	1200	1200	1200
30	1400	1400	1400	1400	1400

Fuel Cost/N Mi In Dollars

Ship Speed	Ship Buoy-Carrying Capacity				
	4	6	8	10	12
9	2. 19	2. 75	2. 75	5. 78	5. 78
12	2. 19	2. 75	2. 75	5. 78	5. 78
15	[illegible]	3. 68	3. 68	5. 78	5. 78
18	4. 38	4. 38	7. 01	7. 01	7. 01
21	7. 51	11. 27	11. 27	11. 27	11. 27
24	16. 43	16. 43	16. 43	16. 43	16. 43
27	23. 37	23. 37	23. 37	23. 37	23. 37
30	30	30	30	30	30

Ship Construction Cost In Millions Of Dollars

Ship Speed	Ship Buoy-Carrying Capacity				
	4	6	8	10	12
9	7. 9	10. 7	11. 6	16. 4	16. 4
12	7. 9	10. 7	11. 6	16. 4	16. 4
15	7. 9	10. 7	11. 6	16. 4	16. 4
18	10. 7	10. 7	16. 4	16. 4	16. 4
21	14. 7	20. 8	20. 8	20. 8	20. 8
24	25. 6	25. 6	25. 6	25. 6	25. 6
27	31. 5	31. 5	31. 5	31. 5	31. 5
30	39	39	39	39	39

In the buoy deployment model, distance traveled on each cruise is determined by computing the great circle distance between port and first buoy deployed, plus great circle distances from buoy to buoy for the remainder of buoys deployed, plus the great circle distance for the return to port.* Navigation points can be interspersed between buoy locations in order to circumnavigate promontories, peninsulas and islands.

Costs for each specified deployment cruise were computed in the manner indicated above and summed over all cruises to give total ship costs for carrying out the deployment of buoys in each MDZ. This value was divided by the number of buoys in the MDZ to determine an average cost per buoy planted, directly attributable to ship operation costs. (In scheduling actual deployment cruises for this study, it was the practice to include some buoys along the boundary line of an adjacent MDZ when needed to assure that all cruises were carried out at full buoy-carrying capacity. Thus, the actual number of buoys deployed per "zone" tended to fluctuate slightly from run to run for some MDZs.)

Ship maintenance costs and fuel costs are shown as functions of both ship speed and buoy-carrying capacity in Fig. 3-1. Note that these graphs clearly indicate that the costs for high speed vessels are independent of buoy-carrying capacity in the range considered. Fig. 3-2 shows comparable curves for ship construction cost. Table 3-3 gives additional information concerning the ship characteristics.

3.2 Buoy Costs

The buoy deployment and maintenance computer model has the facility to compute the cost of each buoy deployed as a function of ocean depth. The required inputs are base cost of the buoy, cost per thousand feet of mooring line, and cost of the mooring-mounted oceanographic sensor packages assumed located at twenty of the International Association of Physical Scientists and Oceanographers (IAPSO) levels from the surface

*In this study the deployment ship always returned to the port from which it departed. The computer program, however, is amenable to the use of separate departure and return ports. In addition, a departure port and a depot at which buoys are on-loaded can be specified as routine inputs to the program. The model has no inherent limitation on number of buoys deployed, ports visited, or navigation points used.

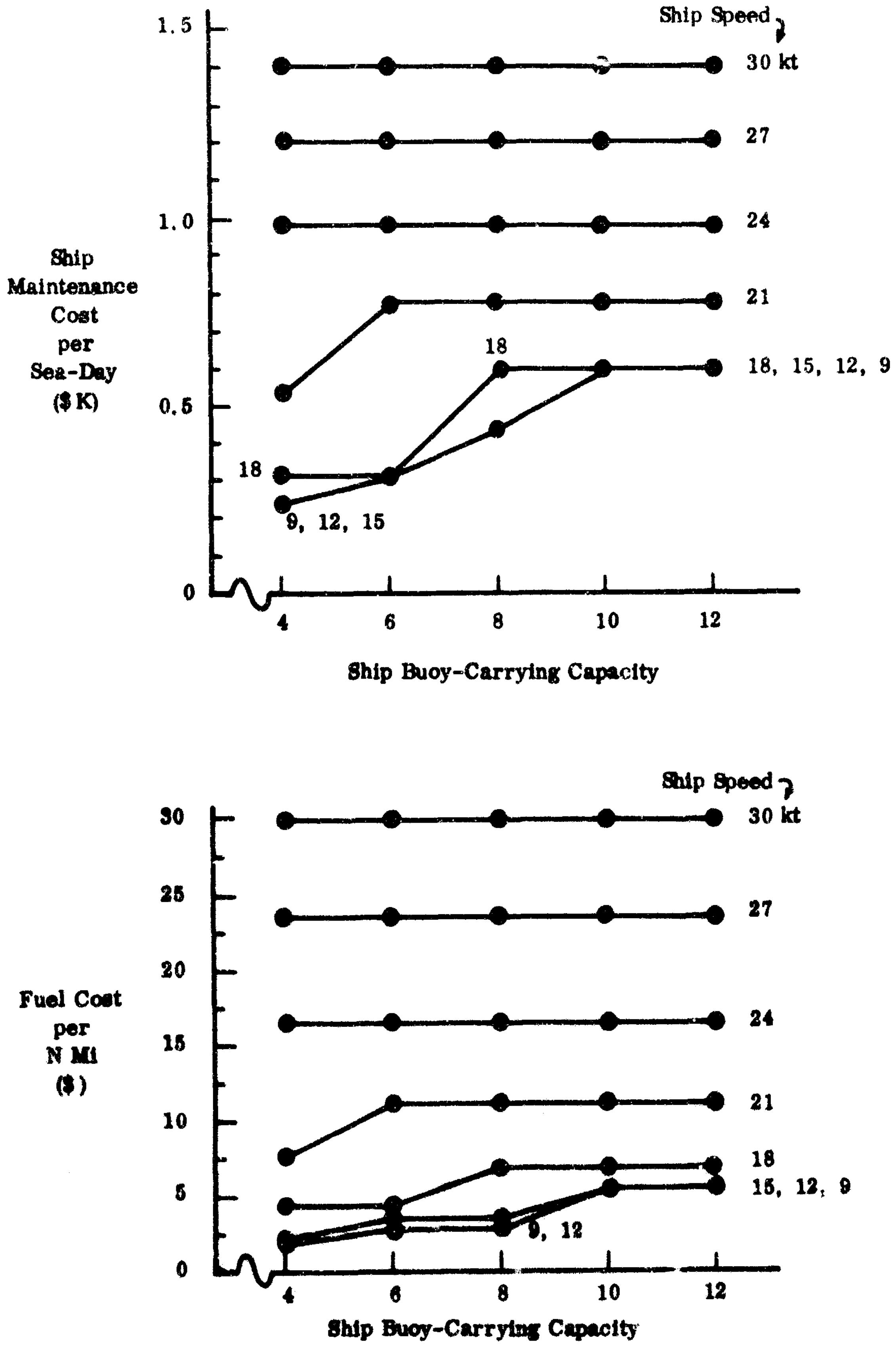


Fig. 3-1. Ship Operating Costs

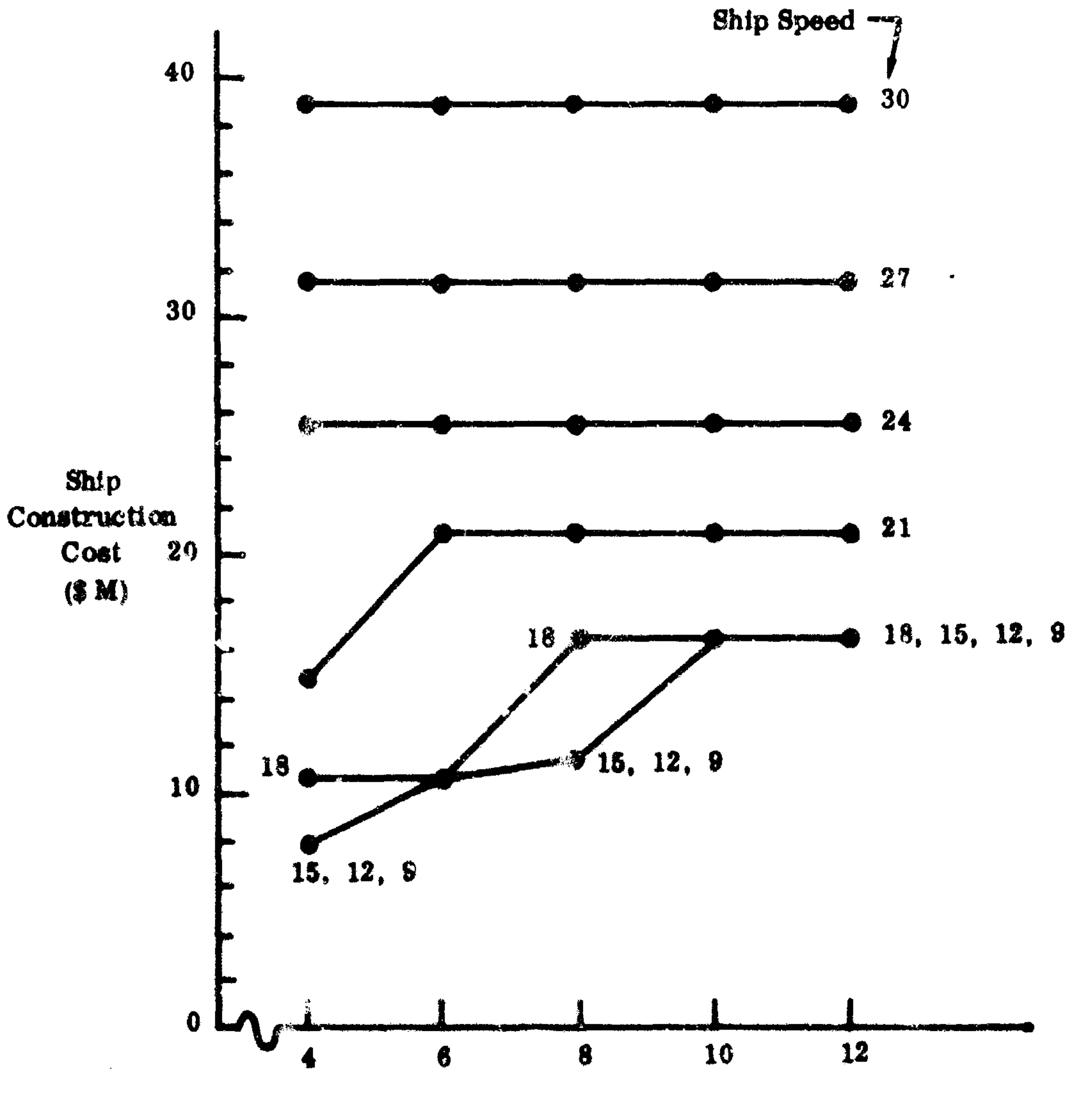


Fig. 3-2. Ship Construction Cost

to 5000 meters depth.* Table 3-4 lists the costs provided by the NDBS DPO for elements of a typical one-point moored 40-ft diameter discus-shaped data buoy capable of one year of unattended operation. These are representative conservatively high costs and are subject to change (in either direction). At the time of completion of this report, the selection of data buoy shape, size, and sensing characteristics has not been made. The representative costs in Table 3-4 have been used only to demonstrate the costing capabilities of the buoy deployment/maintenance cost model.

*The IAPSO levels at which oceanographic instrument packages are assumed located are 0, 10, 20, 30, 50, 75, 100, 150 (2, 3, 4, 5, 6, 8, 10, 15, 20, 30, 40, 50) x 100 meters. When the distance from the last IAPSO level to the bottom is 0.7 or more of the IAPSO increment, an instrument package is assumed to be located near the bottom. Under no conditions does the number of oceanographic sensor packages exceed 20.

TABLE 3-3
NDBS DEPLOYMENT/MAINTENANCE SHIP CHARACTERISTICS

Ship Cost	Ship Length (ft)	Average Ship Speed (kt)	Shaft Horse Power	Loaded Displ. (tons)	Payload (tons)	Buoy Storage Area (ft x ft)	Typical Ship Buoy-Carrying Capacity +
$ 7,900K	250	15	1300	1870	590	114 x 42	4
		12	660				4
		9	390				4
$10,700K	300	18	3000	2700	780	148 x 44	6
		15	2100				6
		12	1060				6
		9	630				6
$11,600K	300	15	2100	3500	1530	148 x 44	8
		12	1060				8
		9	630				8
$14,700K	350	21	6000	3450	690	175 x 50	4
$16,400K	350	18	4800	4950	1930	175 x 50	12
		15	2800				12
		12	1430				12
		9	840				12
$20,300K	400	21	9000	6400	2350	200 x 50	12
$25,600K	450	24	15,000	6800	1730	225 x 50	12
$31,500K	500	27	24,000	8150	1470	250 x 55	12
$39,000K	550	30	40,000	9400	1300	275 x 55	12

+At the time of preparation of this report, the size and shape of NDBS data buoys had not yet been selected.

TABLE 3-4
HARDWARE COSTS FOR 40-FT DISCUS BUOY*
40-Foot Discus

Item	Cost (Dollars)
40' Discus Hull	80000
Mooring/100 Ft.	175**
40' Power System	10000
Data Storage	10000
Data Proc. - Scan.	15000
Time Control	1000
Buoy Telemetry	15000
Fuel Supply	200
Mooring Tension	500
Hull Temp.	100
Bilge Water Lvl	50
Mag. Heading	300
Anchor Release	2500
Anchor, Chain, Etc.	1000
Nav. Radio Beacon	5000
Nav. Light/Horn	500
Ambient Noise	1000 (2)
Ambient Light	1700 (2)
Transparency Sensor	1100
Wave Sensor	6250
Atmos. Press. Sensor	500
Air Temp. Sensor	400
Dew Point Sensor	1300
Wind Velocty Sensor	600
Precip. Rate Sensor	500
Insolation Sensor	500
Atmos. Elec. Sensor	1000
Subsurface Sensor Pkg.	7000**each

Basic Buoy Cost = $158,200

Mooring Cable = $1,750/1000 ft

Subsurface Sensor Package = $7,000 each

*These representative costs are not to be used for financial planning purposes.
**Not included in basic (non-depth dependent) cost.

4.0 NUMBERS AND GEOGRAPHICAL LOCATIONS OF DATA BUOYS

It is emphasized that the primary purpose of this study is to determine statistically useful results to support development planning in the NDBS DPO. For example, the sensitivity of costs to locations of buoys and deployment/maintenance ports is of fundamental importance in defining ship design parameters such as ship speed and buoy-carrying capacity. It is of interest to have an accurate count of total length of mooring line required, total number of oceanographic sensor packages needed, and total cost of buoy hardware deployed in various geographical regions. These and other results from this study are useful for development planning at this time. Clearly, the choice of actual locations for deployment of buoys will require inputs from all government agencies (and the data users they represent). Buoy locations used in this study are, therefore, to be considered only as representative of both grid spacings and choice of locations that may ultimately be selected. The statistical results from this study, however, are believed to be relatively independent of the selection of sites, as will be made clear in Section 5.

4.1 Constraints and Summaries of Buoy Locations

For the purposes of this study, the USCG NDBS DPO specified the characteristics of the baseline data buoy system to be 500 buoys uniformly distributed in a 500 n mi grid in the Deep Oceans of the northern hemisphere between the equator and 60°N latitude and in a uniform 100 n mi grid in the Coastal North American regions out to 400 n mi from shore. These grid spacings resulted in 150 Deep Ocean buoys and 350 Coastal North American buoys. Certain northern hemisphere geographical areas were proscribed by the NDBS PMO for deployment of buoys:

- The region between the equator and the southern coast of Africa
- The Mediterranean Sea
- The Sea of Okhotsk
- Regions adjacent to the coast of Communist China.*

To place the results of the buoy deployment study on a statistically comparative basis, it was elected to divide the Deep Ocean regions of the world into a total of

*These proscribed areas were avoided in all buoy deployments.

seven Modular Deployment Zones (MDZ), of which three are in the northern hemisphere. The Coastal North American region was divided into six Modular Deployment Zones. The thirteen MDZs are shown in Figure 4-1. For the northern hemisphere 500-buoy baseline system, approximately 50 to 60 buoys are located in each of the nine northern hemisphere MDZs.

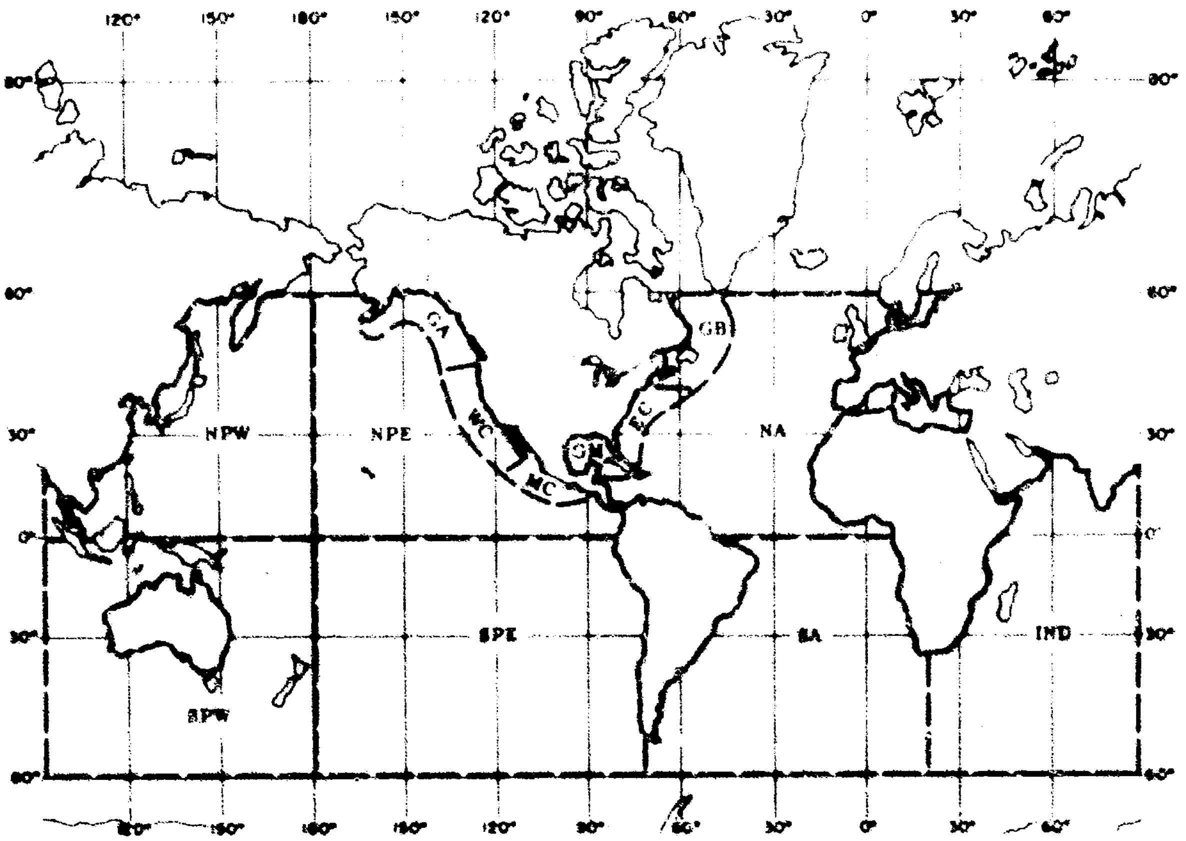


Fig. 4-1. National Data Buoy Systems Modular Deployment Zones

The NDBS DPO selected Portsmouth, Virginia; San Francisco, California; and Honolulu, Hawaii as representative deployment port locations, suitable for this initial study. The MDZs served by these three deployment ports are given in Table 4-1 below.

At the direction of the NDBS DPO, seven northern hemisphere data buoy deployment configurations have been investigated in this study. Beginning with the 500-buoy uniform-grid baseline system, the remaining six deployment configurations are based on successively smaller percentages of the baseline system deployed according to a series of different rationales. A three-fourths of baseline system (375 buoys) was deployed in a 600 n mi Deep Ocean grid (100 buoys) and a variable 100 to 150 n mi Coastal North American grid (275 buoys). These grid spacings were determined, in a TRC effort carried out in parallel with this study, as those most applicable for an initial NDBS. Government agencies stating requirements for meteorological and oceanographic data concurred with these grid spacings [3]. With the exception of the North Pacific West and East Coast MDZs, the 375-buoy deployment results in each MDZ holding approximately three-fourths of the number of baseline buoys in each MDZ.

Two 250-buoy deployment configurations were prepared. They represent one-half baseline systems. In one of these configurations, the location of buoys was left much to the discretion of the "system designer," and the preponderance of the total number of buoys was placed in MDZs in which it was considered deployment of buoys would be of high economic benefit and cost of deployment would be held to a minimum. MDZs in which location of buoys might not be of comparable economic benefit hold a smaller percentage of baseline buoys. The second 250-buoy configuration was constrained in each MDZ to have exactly 50 per cent of the number of baseline buoys. The actual locations of buoys within the MDZs was left to the discretion of the "system designer," as before.

TABLE 4-1
DEPLOYMENT PORTS AND MODULAR DEPLOYMENT ZONES

Region	Modular Deployment Zone		Deployment Port
Coastal North America	Grand Banks	(GB)	Portsmouth, Virginia
	East Coast	(EC)	Portsmouth, Virginia
	Gulf of Mexico	(GM)	Portsmouth, Virginia
	Mexican Coast	(MC)	San Francisco, California
	West Coast	(WC)	San Francisco, California
	Gulf of Alaska	(GA)	San Francisco, California
Northern Hemisphere Deep Oceans	North Pacific East	(NPE)	Honolulu, Hawaii
	North Pacific West	(NPW)	Honolulu, Hawaii
	North Atlantic	(NA)	Portsmouth, Virginia

Using the same two rationales outlined above — unconstrained deployment and deployment constrained to a fixed percentage of baseline buoys in each MDZ — two 125-buoy configurations were established. In the unconstrained case, location of all 125 buoys was left to the discretion of the "system designer." In the second case, each MDZ contained 25 per cent of the baseline buoys previously located in the MDZ.

The final buoy configuration provided only 12 per cent of baseline (60 buoys). There was a total of 36 buoys in the eastern region and 24 buoys in the western region with 56 of these buoys located in the CNA regions and 4 buoys (3 east coast, 1 west coast) located in adjacent DO MDZs. All locations were left to the discretion of the "system designer." The above comments are summarized in Table 4-2. The remainder of this section describes in some detail the rationales behind the location of buoys in the seven deployment configurations used in this study.

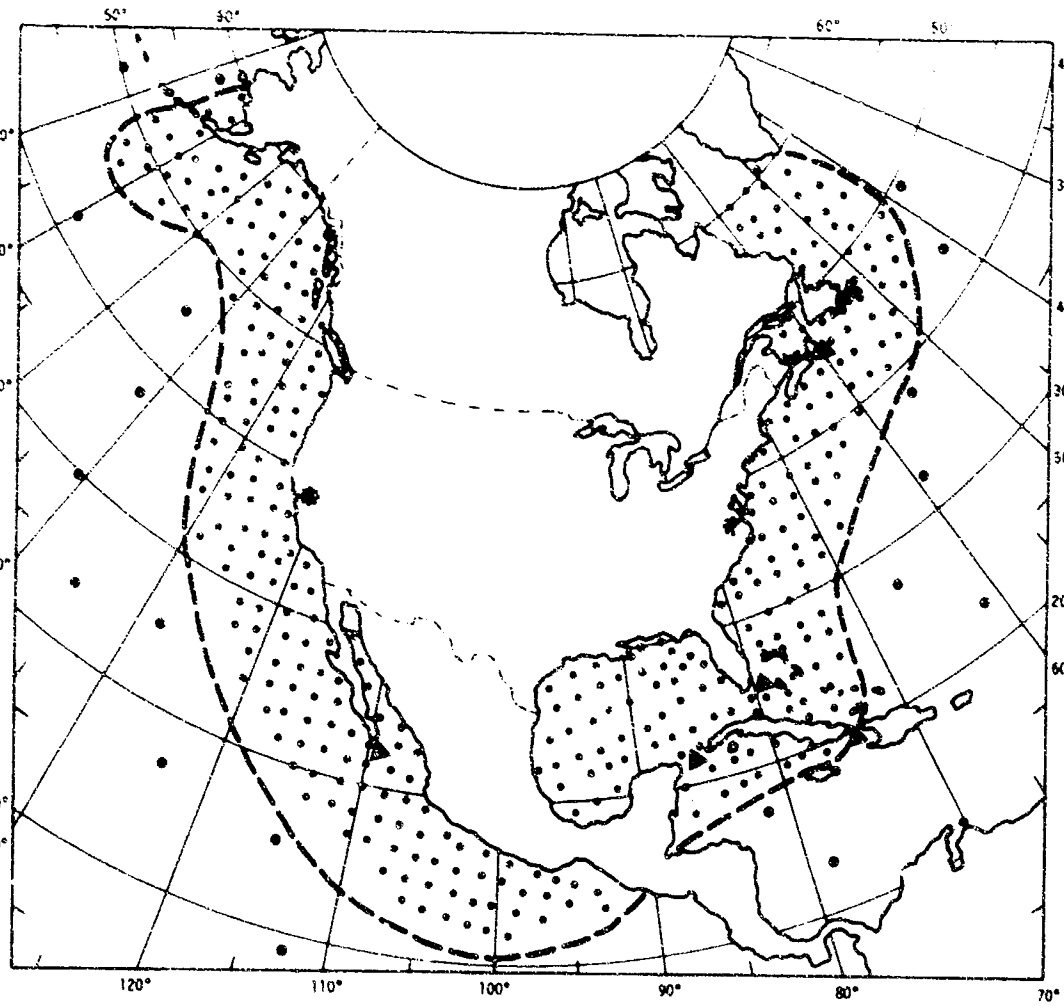
The next five sub-sections describe the seven deployment configurations in greater detail.

TABLE 4-2
BUOYS DEPLOYED IN MODULAR DEPLOYMENT ZONES

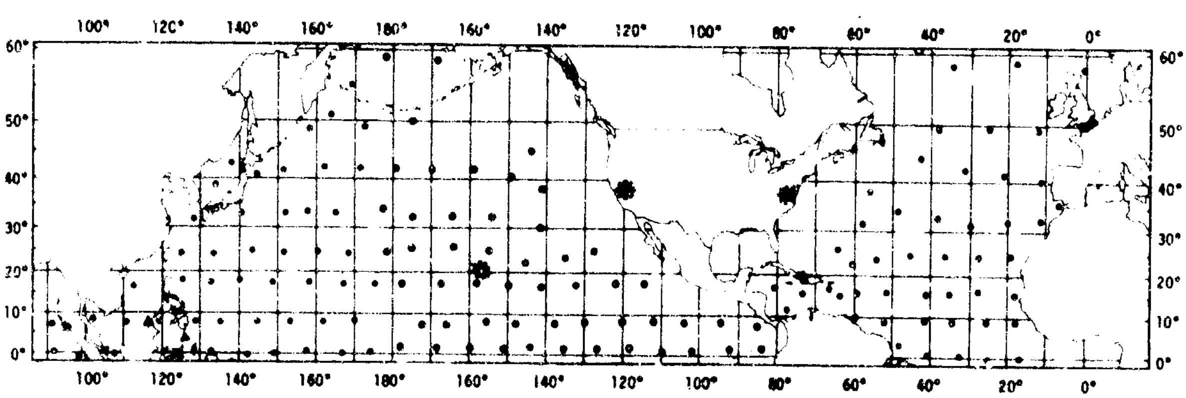
Modular Deployment Zone	Buoy Systems						
	500 (Baseline)	375	250	50% Baseline	125	25% Baseline	60
Grand Banks	56	40	17	28	8	14	4
East Coast	53	53	49	27	29	13	18
Gulf of Mexico	60	52	36	30	20	15	12
Mexican Coast	60	38	8	30	3	15	0
West Coast	67	48	33	33	23	17	15
Gulf of Alaska	54	44	24	27	15	14	7
CNA Total	350	275	167	175	98	88	56
North Pacific West	53	29	16	26	0	13	0
North Pacific East	49	35	34	25	13	12	1
North Atlantic	48	36	33	24	14	12	3
DO Total	150	100	83	75	27	37	4
Grand Total	500	375	250	250	125	125	60

4.2 The 500-Buoy Baseline System

The 500-buoy baseline system, shown in Fig. 4-2, was derived in part from the summary of national requirements for marine meteorological and oceanographic data collected as part of the 1967 NDBS Feasibility Study. In the 500-buoy deployment, little or no emphasis has been given to locating of buoys to satisfy unique data needs from specific areas. Nor has positioning of buoys to satisfy potential economic benefits or to hold down deployment costs been introduced in an express fashion. The 500-buoy system was based on composite 1967 national operational data requirements from many government agencies specifying need for data from 100 n mi grid points in the Coastal North American regions and 500 n mi grid points in the Deep Oceans of the world. As will be discussed in the next section, refinement and re-assessment of 1967 data requirements has indicated that a lesser number of buoys in the northern



a. Coastal North America Data Buoy Locations (350)



b. Deep Ocean Data Buoy Locations (150)

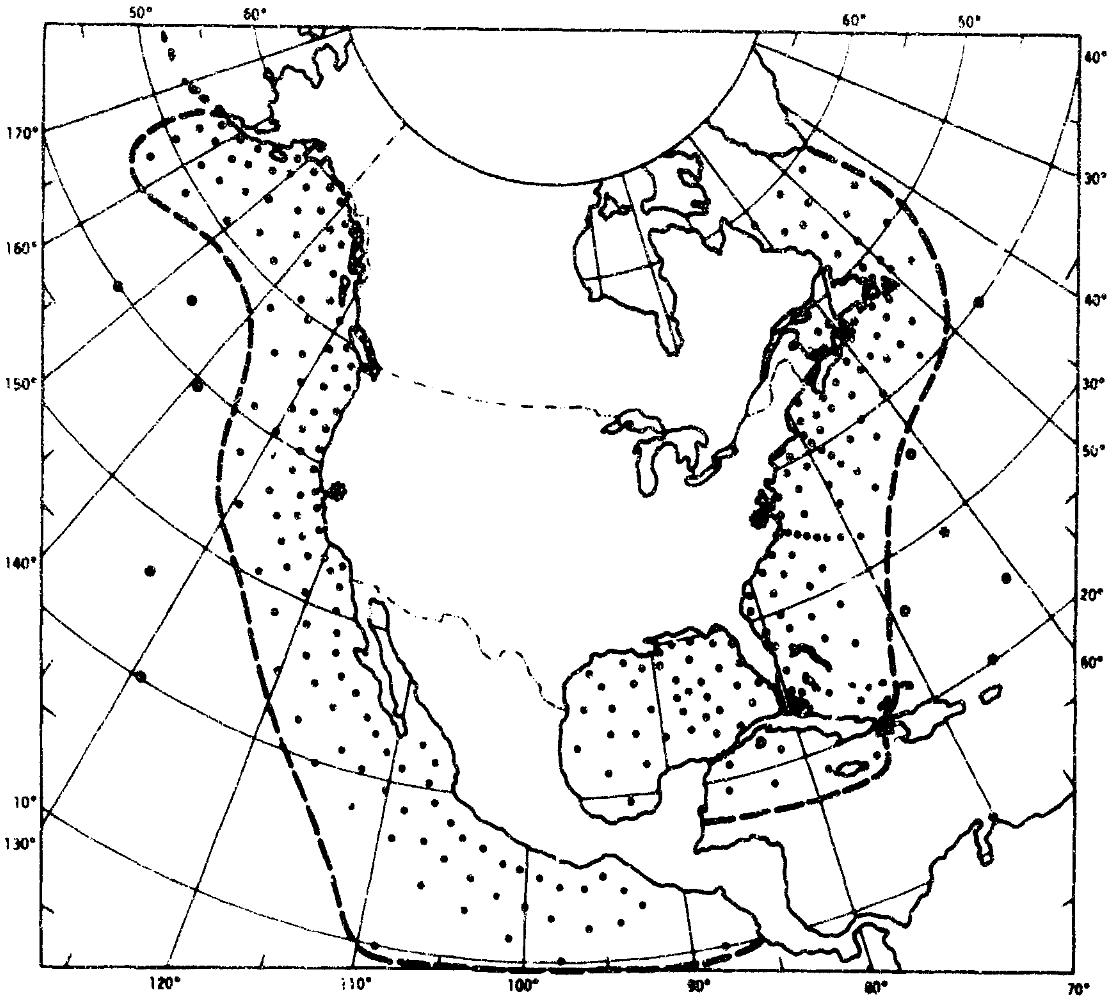
Fig. 4-2 Data Buoy Locations for the 500-Buoy System (Baseline)

hemisphere might be adequate for initial satisfaction of requirements. Hence, the 500-buoy northern hemisphere deployment appears to be a reasonable upper bound on system size for consideration at this time. Systems with lesser numbers of buoys can be taken as representative of the likely evolutionary growth national data buoy systems are apt to undergo. Because of the large number of buoys in the 500-buoy baseline system, it appeared that uniform grid spacings for the baseline system would be best for development of statistical comparisons with configurations of fewer buoys.

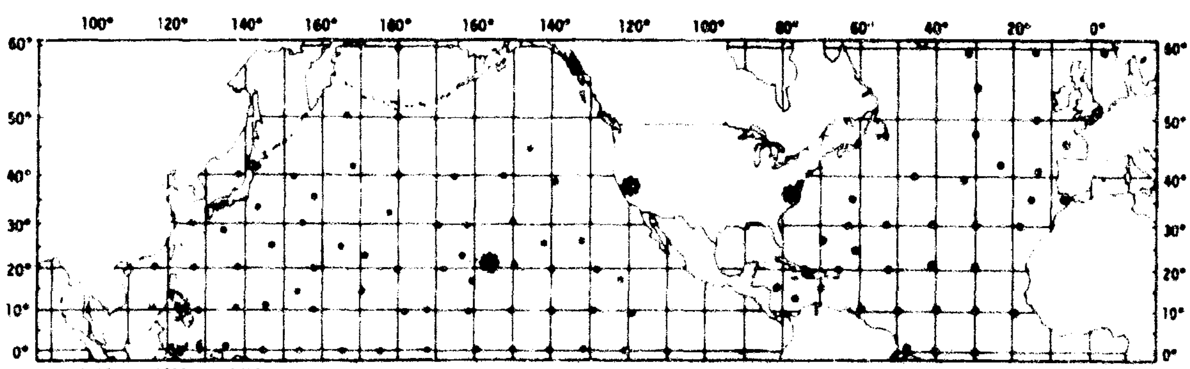
4.3 The 375-Buoy System

In the 375-buoy system, shown in Fig. 4-3, specific attention has been given to satisfying U. S. government agency requirements that were reviewed and refined (by the agencies) during 1968. These resulted in a 600 n mi grid for the Deep Oceans and a variable 100 to 150 n mi grid in CNA, and need for buoys at a number of selected sites. In Fig. 4-3, buoys in the innermost row of CNA buoys are approximately 25 n mi from shore and approximately 100 n mi apart. The next row is approximately 100 n mi from the first and about 112 n mi apart. The third row is 125 n mi beyond the second and these buoys are 125 n mi apart. The fourth row extends 150 n mi beyond the third and the buoys are 150 n mi apart. The above comments hold for all CNA MDZs with the exception of the Mexican Coast. There, the buoys in the first row are 100 n mi from shore and 100 n mi apart. The second row is 150 n mi beyond the first and has buoys 125 n mi apart. The third and last row is 150 n mi from the second and those buoys are 150 n mi apart. These comments are summarized in Fig. 4-4.

As is evident from Fig. 4-3, not all CNA buoys are located in the variable grid described. In the Grand Banks MDZ, fishing and shipping interests in the Gulf of Maine and on the Grand Banks have been recognized. The Labrador Current is monitored up through the Davis Strait; the ice patrol area below Newfoundland continues to receive good coverage. Certain CNA buoys are located to meet specific requirements such as the transect lines in the East Coast MDZ, where buoys are deployed to monitor the flow of the Gulf Stream and to detect typical extra-tropical cyclonic disturbances that originate in the southeastern U. S., or off-shore, then move out to sea and up the U. S. eastern seaboard. Additional transect lines are indicated across the

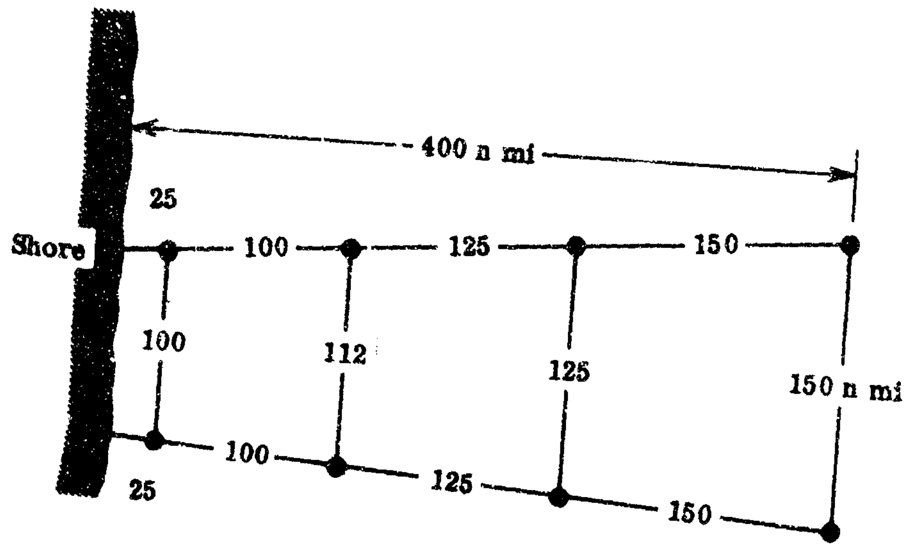


a. Coastal North America Data Buoy Locations (275)

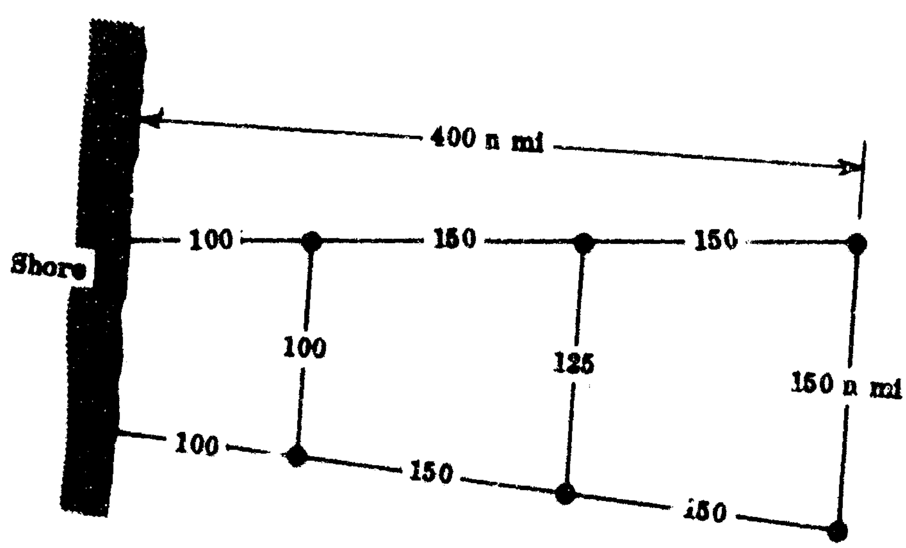


b. Deep Ocean Data Buoy Locations (100)

Fig. 4-3 Data Buoy Locations for the 375-Buoy System



a. Coastal North America Buoy Spacing, Except Mexican Coast MDZ



b. Mexican Coast MDZ Buoy Spacing

Fig. 4-4. Coastal North America Buoy Spacings

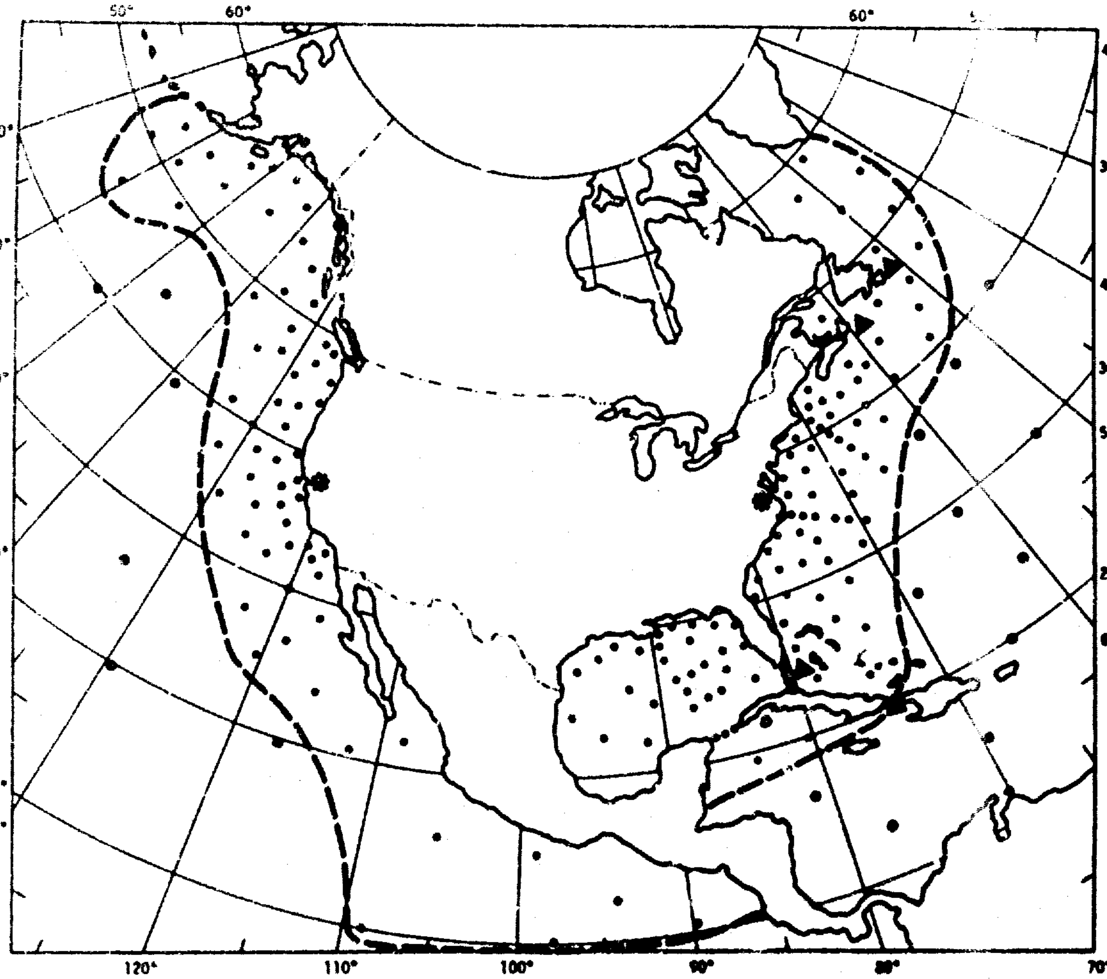
Florida Straits and the Yucatan Channel. In the Gulf of Mexico, buoys are located off the Louisiana and Texas coasts to provide meteorological information for the off-shore oil and gas industry and the shrimp industry. The Gulf of Mexico gyre is monitored by means of eight buoys in a square, north of the Yucatan Straits. Some buoys serve the USAF test range in the eastern section of the Gulf. Other buoys are placed in locations providing data that would serve the U. S. fishing industry and the general needs of local inland and maritime weather and marine forecasting and hurricane warning.

Buoys off the Mexican coast are located primarily to provide oceanographic and meteorological information for the fishing industries. Extending northward along the U. S. west coast, CNA buoys would provide data useful for inland and near-shore meteorological purposes, off-shore oil and gas in the vicinity of Santa Barbara, other mineral resources, and commercial and sports fishing. Some northernmost West Coast MDZ buoys are deployed to satisfy a requirement to monitor the out-flow of the Columbia River. In the Gulf of Alaska, meteorology and fishing are of primary importance, with coastal buoys of use to off-shore mineral operations (one buoy has been specifically located in Cook Inlet to provide information useful for oil and gas exploration and production operations).

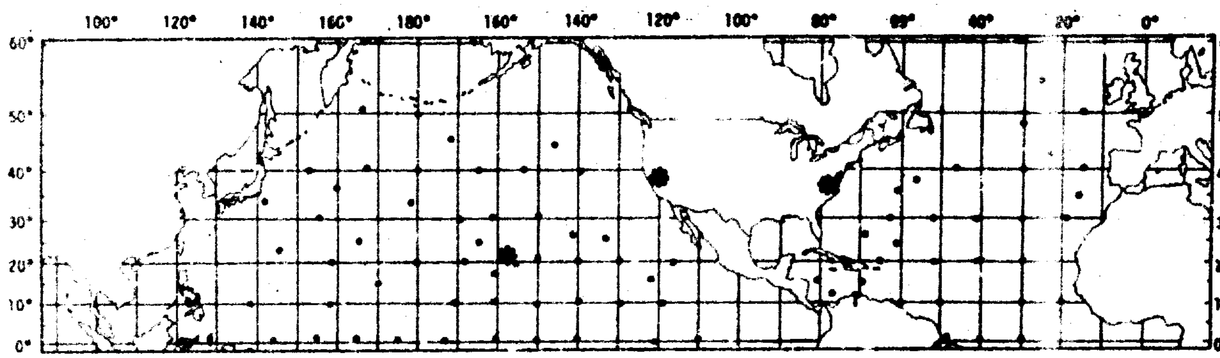
In the Deep Ocean regions, it has been tacitly assumed that existing ocean weather stations would continue to operate with manned vessels, and buoys are not located near those points. Buoys are located along 150° W to satisfy Air Force range requirements. Other buoys appear along standard transect lines between the U. S. coastline and Hawaii. In the North Pacific and the North Atlantic, buoys are shown at points from which data would be useful for optimum ship tracking routing (OSTR), and long-range weather forecasting. Buoys are located in the Caribbean and southeast of the U. S. coast line in positions useful for monitoring hurricanes and oceanographic currents.

4.4 The Two 250-Buoy Systems: Unconstrained and Constrained

In this discussion, the following two definitions will be used. The 250-buoy system deployed at the discretion of the "system designer" will be called the "unconstrained" system. The deployment, having in each MDZ 50 per cent of the baseline number of buoys in that MDZ, will be called the "constrained" system. The unconstrained deployment shown in Fig. 4-5 will be discussed first.



a. Coastal North America Data Buoy Locations (167)



b. Deep Ocean Data Buoy Locations (83)

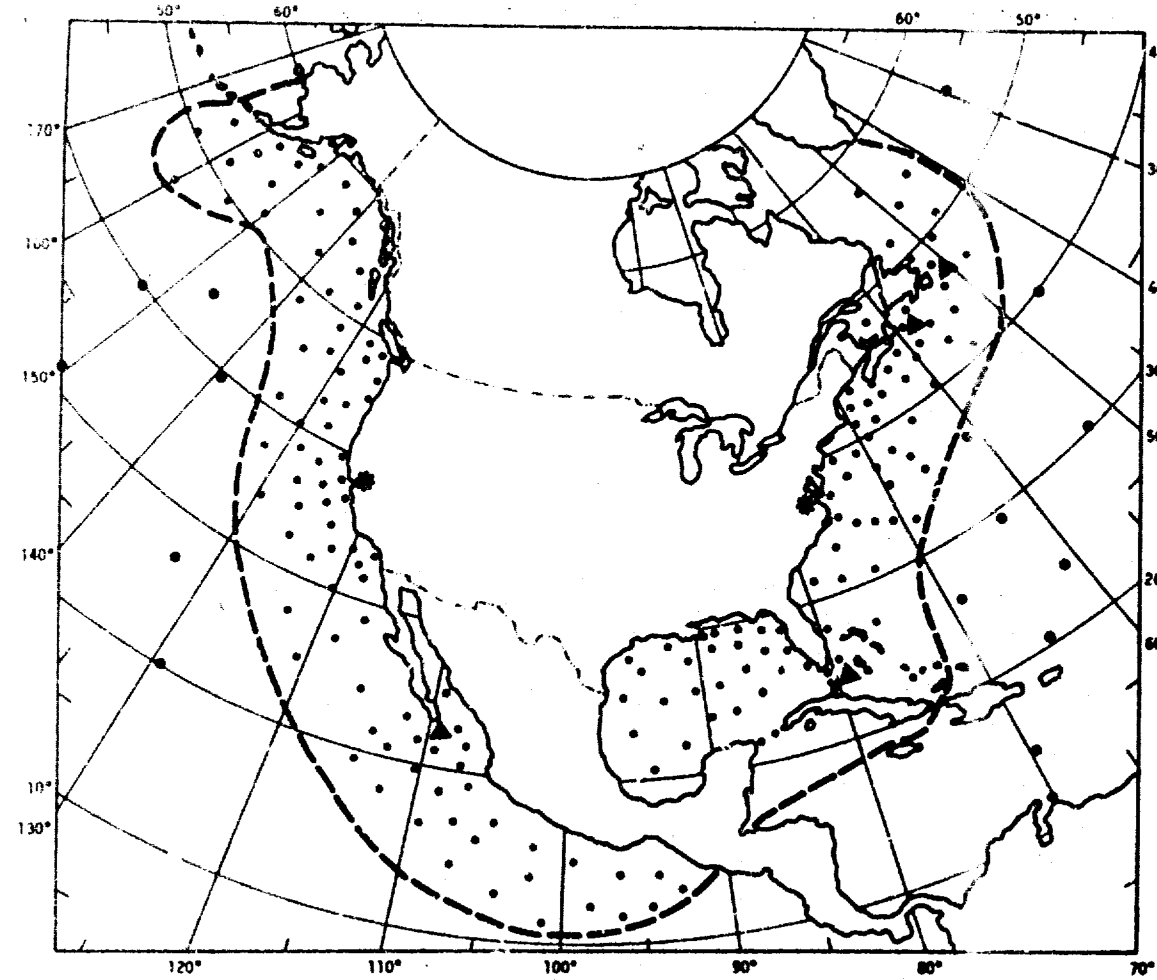
Deployment Port
Navigation Point

Fig. 4-5 Data Buoy Locations for the 250-Buoy System (Unconstrained)

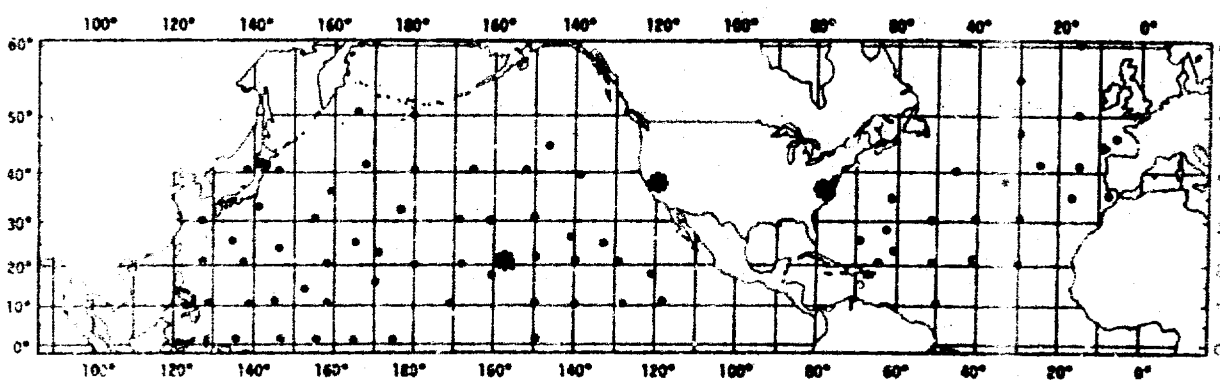
In the Deep Oceans, buoys at great distances from U.S. deployment ports have been eliminated, e.g.; in the North Sea, off the shores of Europe and Africa, and off the shores of Asia. Throughout the North Pacific East MDZ, the eastern side of the North Pacific West MDZ and most of the North Atlantic MDZ buoy spacings of approximately 600 n mi have been maintained. Buoys are not located at those points presently being covered by ocean station vessels. Ocean currents, typhoon and hurricane tracks, and some military ranges in the Deep Oceans have been considered in the process of locating buoys. Collection of data to support optimum ship track routing has also been taken into consideration.

In the Coastal North American region, only eight buoys have been located in the Mexican Coast MDZ, partly because of the high cost of deployment from the specified port of San Francisco, and partly as a function of allocating buoys to potentially more (economically) beneficial areas. Less buoys than 50 per cent of baseline have been allocated to the Gulf of Alaska and the Grand Banks. More buoys than 50 per cent of baseline appear in the East Coast and Gulf of Mexico MDZs and exactly 50 per cent of baseline is positioned in the West Coast MDZ. As before, these buoys are located to serve off-shore oil and gas, and commercial and sports fishing interests, in addition to providing transect data for monitoring marine meteorological and oceanographic phenomena in the CNA region for forecasting. For example, Gulf Stream transects still exist in the East Coast MDZ, and in the Gulf of Mexico MDZ; transects for the Straits of Florida and the Yucatan Channel are still in being, although each has been reduced by one buoy. The Gulf of Mexico gyre continues to be monitored, as do certain out-flow properties of the Columbia River.

The constrained 250-buoy configuration shown in Fig. 4-6 indicates the effect of keeping a larger number of buoys in the Mexican Coast, Grand Banks, and Gulf of Alaska MDZs; thus serving better the fishing interests in these zones. Previously in the unconstrained 250-buoy configuration, these areas had provided buoys used to augment the North Atlantic, North Pacific East and North Pacific West Deep Ocean MDZs. The constrained configuration affords fewer buoys for the East Coast and Gulf of Mexico MDZs; thus reducing the fineness of transect monitoring and Gulf of Mexico gyre monitoring. As in the unconstrained configuration, there is a buoy in Cook Inlet, Alaska, for oil and gas purposes, and there are buoys for monitoring the out-flow of



a. Coastal North America Data Buoy Locations (175)



b Deep Ocean Data Buoy Locations (75)

Deployment Port

Navigation Point

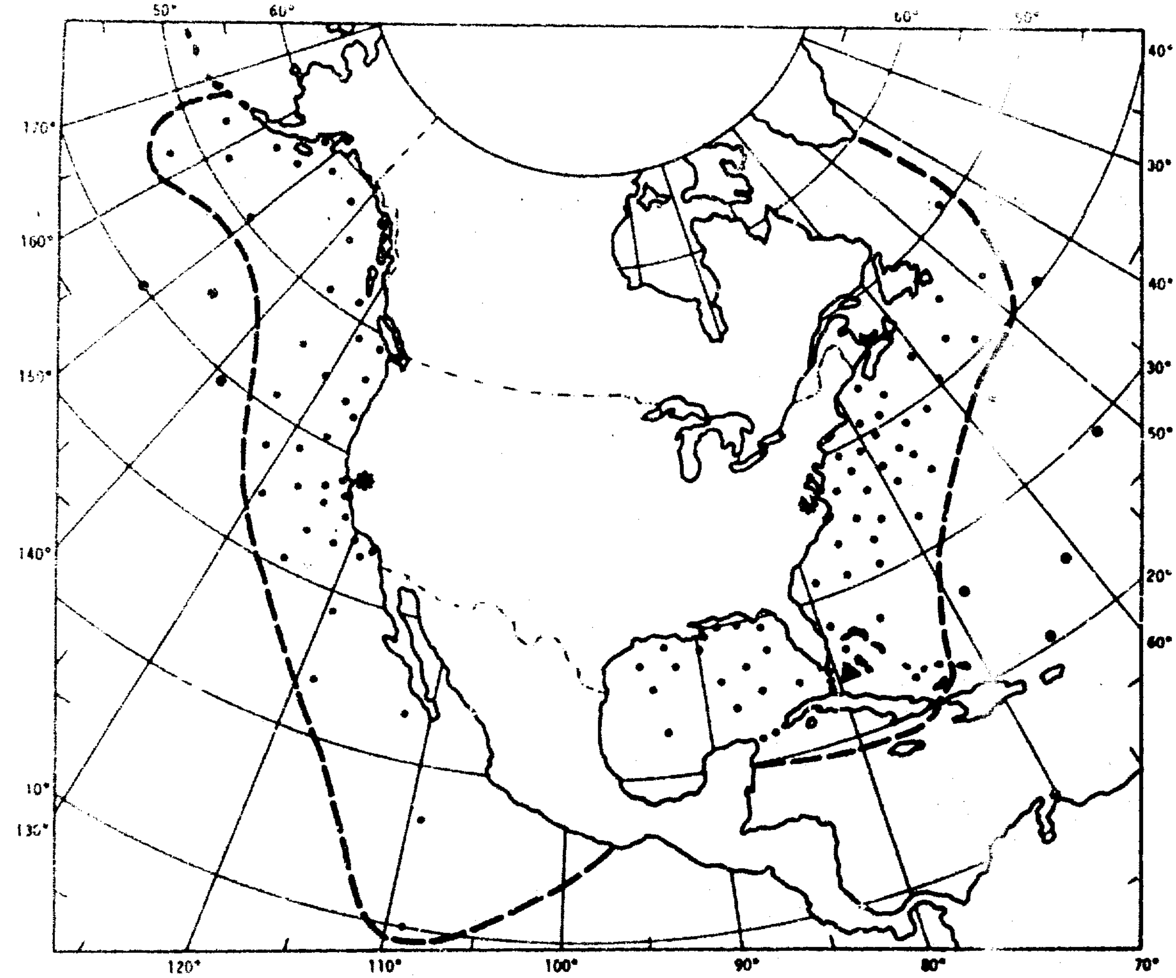
Fig. 4-6 Data Buoy Locations for the 50 Percent Buoy System (Constrained)

the Columbia River. Buoys are provided for marine meteorological and oceanographic monitoring and prediction purposes in all MDZs.

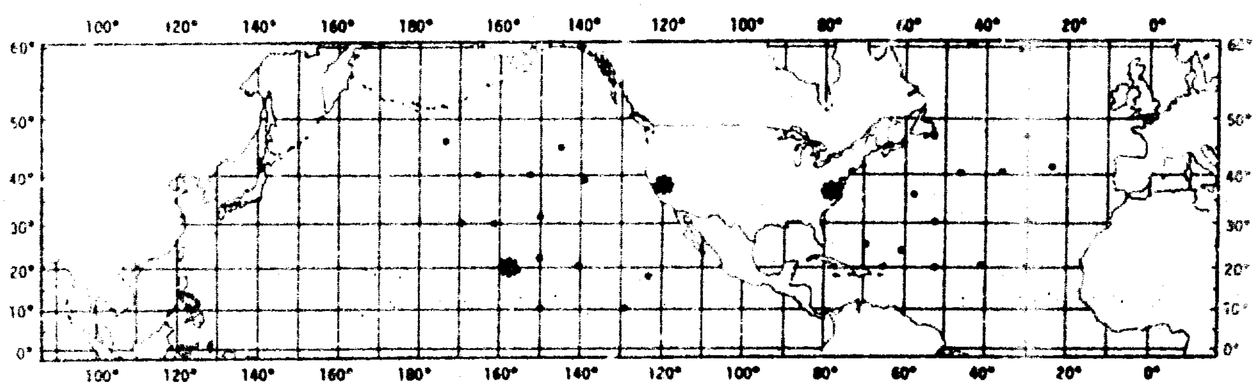
4.5 The Two 125-Buoy Systems: Unconstrained and Constrained

Definitions of "unconstrained" and "constrained" buoy configurations used here are the same as those in the previous section. The principal features of the 125-buoy unconstrained system shown in Fig. 4-7 are the elimination of deployments in the North Pacific West MDZ and the virtual elimination of buoys in the Mexican Coast MDZ. North Pacific East and North Atlantic buoys are reduced to 13 and 14 buoys respectively. In the North Atlantic MDZ, buoys are deployed primarily to provide marine meteorological and oceanographic data along principal shipping routes and storm tracks between the U. S. and Europe and to monitor the generation and growth of hurricanes in the southwest Atlantic. In the North Pacific East MDZ, the principal rationale for deployment has been the provision of marine meteorological and oceanographic data for weather prediction purposes — both long-range predictions for inland U. S. areas and short-range predictions for shipping, fishing, and CNA coastal regions.

The Coastal North American MDZs in the 125-buoy unconstrained system reflect the assumed higher priority for data directly off the east and west coasts of the U. S. A line of buoys in the Gulf of Alaska, approximately 100 to 150 n mi from shore, provides monitoring for short range weather prediction. A much coarser group of buoys, 400 n mi from shore, has also been provided. Cook Inlet, the Columbia River out-flow, the regions west of San Francisco and Santa Barbara, and the region west of the Southern California megalopolis have all been given as much consideration as this small number of buoys permits. In the Gulf of Mexico, monitoring continues on a reduced scale in the Yucatan Channel and the Florida Straits. Nearshore fishing and oil and gas interests in the Gulf of Mexico continue to be served. Buoys in the vicinity of the southwestern Gulf of Mexico MDZ no longer appear. Off the U. S. east coast the density of buoys has been held reasonably high, serving shipping interests, fishing interests and marine meteorological and oceanographic observation for short-range prediction. The Grand Banks MDZ now includes only eight buoys, none of which appears in Davis Strait, leaving only approximately three or four that could be considered effective in monitoring the Labrador Current. Only one buoy remains in the



a. Coastal North America Data Buoy Locations (98)



b. Deep Ocean Data Buoy Locations (27)

Deployment Port

Navigation Point

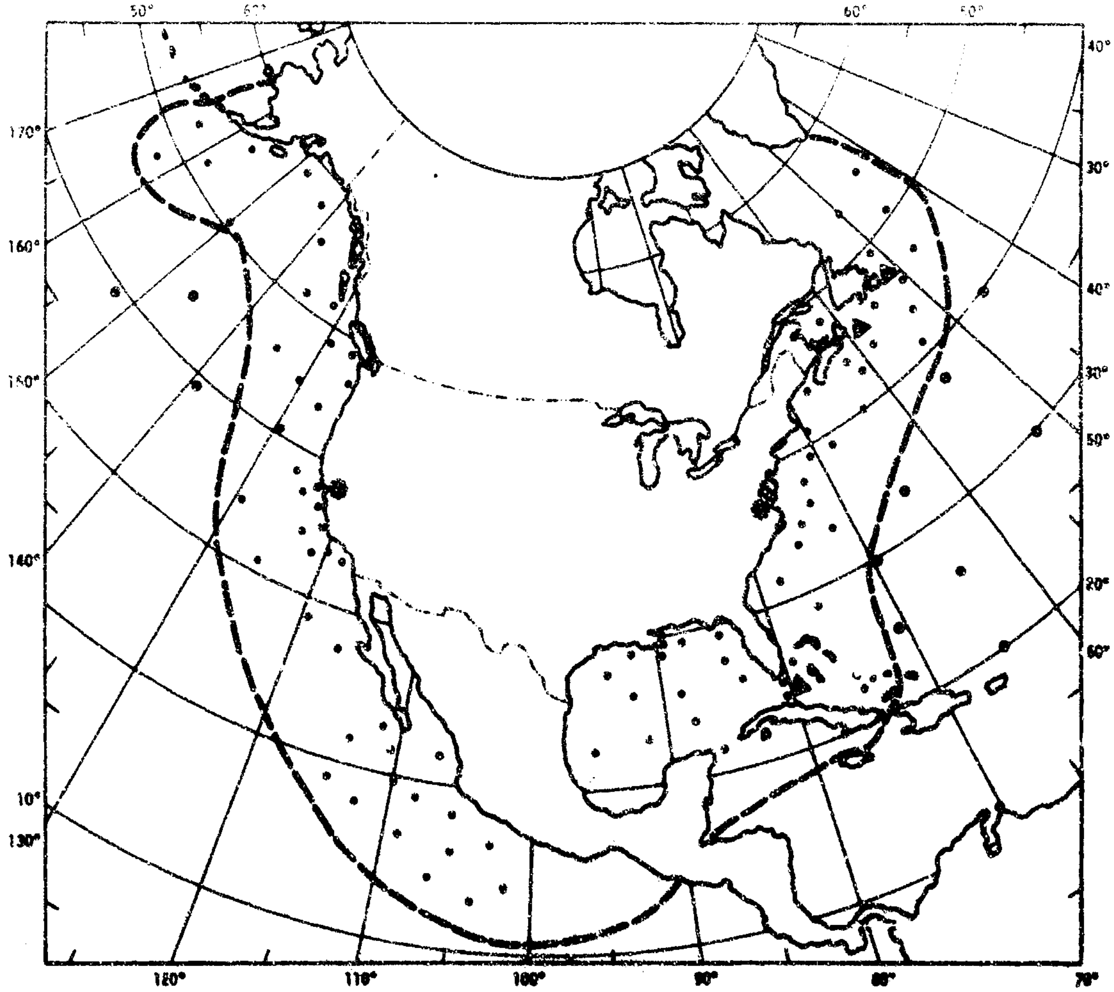
Fig. 4-7 Data Buoy Locations for the 125-Buoy System (Unconstrained)

Gulf of Maine. The Grand Banks fishing area and the ice patrol area are still served, but to a lesser degree than previously. Though reduced in number, the buoys are in position to provide useful meteorological monitoring of blocking high pressure systems.

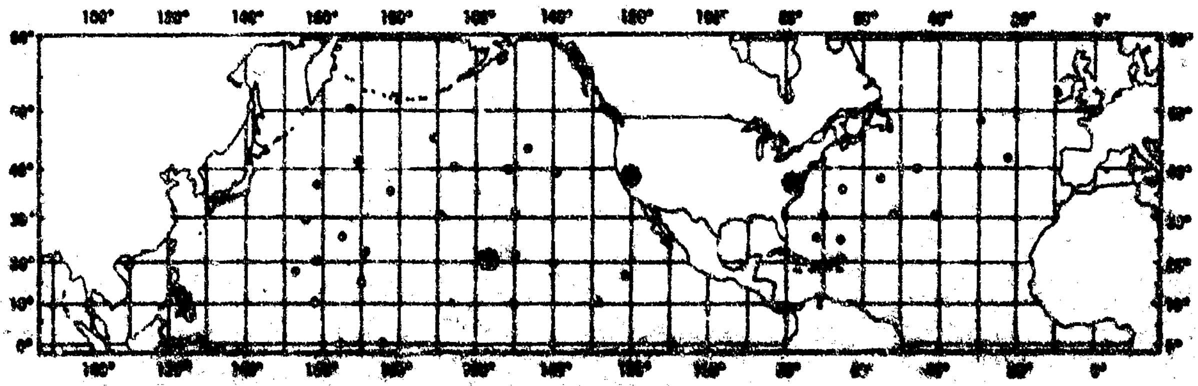
Fig. 4-8 shows the 125-buoy constrained deployment configuration. In this case 13 buoys are required in the North Pacific West MDZ and are arranged to provide from the Central North Pacific meteorological and ocean-current information, especially the monitoring of typhoons. The North Pacific East and West configurations are deployed with consideration to the location of present ocean station vessels and the potential to monitor meteorological conditions from islands (which do not appear in the figure). The 12 North Pacific East buoys primarily serve ocean transportation and long-range meteorological prediction interests, although some U.S. Air Force and U.S. Navy range requirements have also been considered. In the North Atlantic MDZ, coverage of storm tracks and the principal shipping route between the U.S. and Europe have been the principal considerations, along with deployment of buoys north of Puerto Rico for hurricane monitoring and to serve shipping and sports fishing. With 25 per cent of baseline buoys in each CNA MDZ, east and west coast coverage is much reduced from the unconstrained 125 buoy configuration. The same is true for the Gulf of Mexico MDZ. Monitoring of the Yucatan Channel and the Florida Straits has become minimal. Little or no resolution of the Gulf of Mexico gyre can now be expected, but Continental Shelf fishing interests in the Gulf of Mexico continue to be served in essentially the same fashion as previously. More buoys are located in the Grand Banks MDZ than was the case for the unconstrained configuration and buoys now extend up in the Davis Strait, giving better coverage of iceberg regions, the Labrador Current, and to the south the Grand Banks fishing area.

4.6 The 60-Buoy System

The 60-buoy system, shown in Fig. 4-9, is an unconstrained deployment, as defined in Section 4.4. Twenty-four buoys are located off the west coast of continental North America and thirty-six off the eastern and southern coast of continental North America. Only four of these buoys fall in Deep Ocean MDZs, and those locations are only slightly beyond the 400 n mi CNA boundary. No buoys are located in the Mexican Coast MDZ and only four are found in the Grand Banks MDZ. The U.S. West



a. Coastal North America Data Buoy Locations (56)

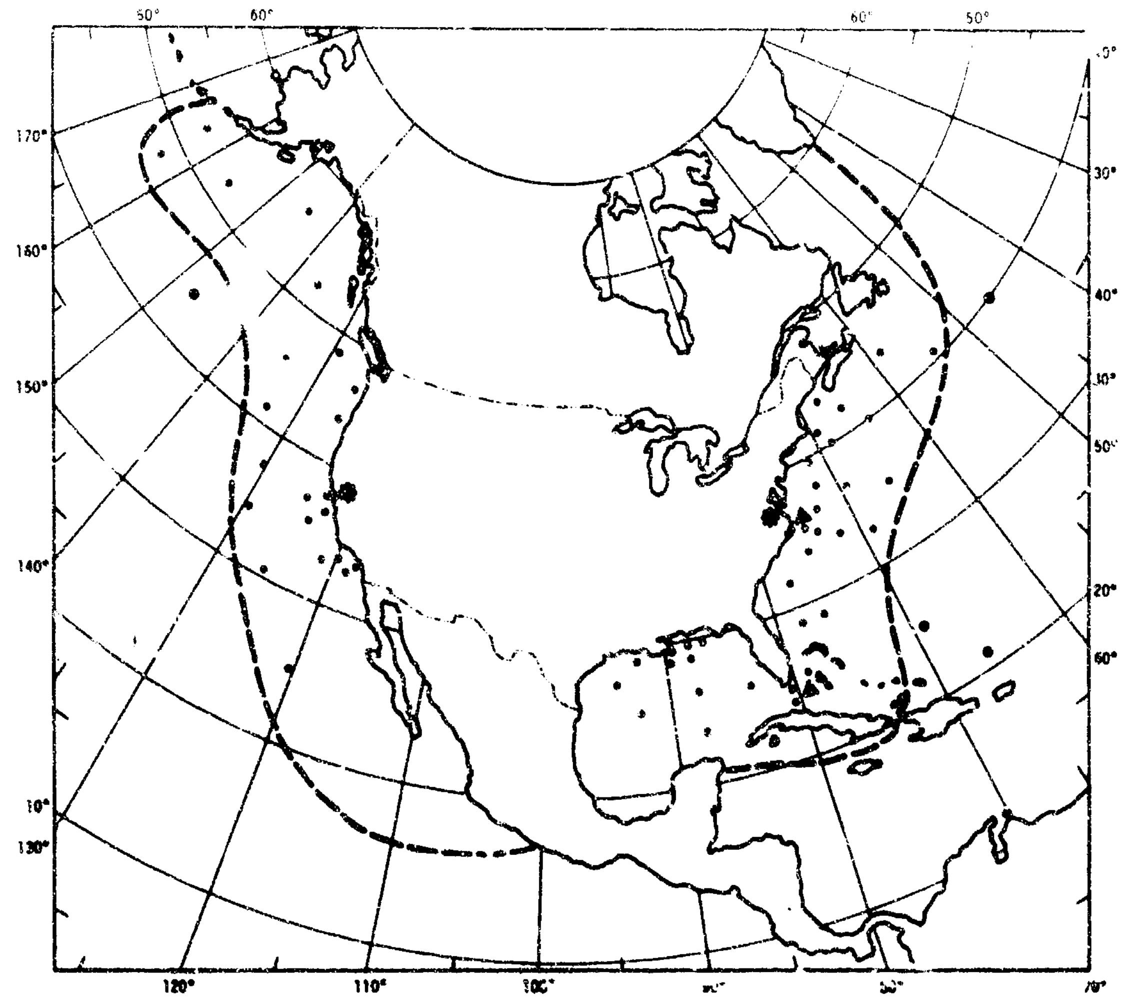


b. Deep Ocean Data Buoy Locations (37)

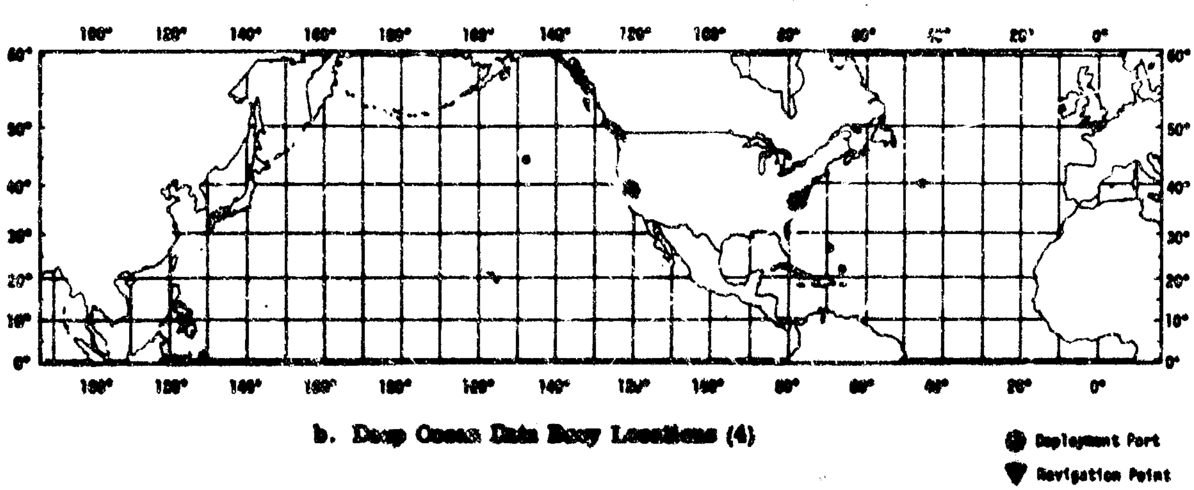
Deployment Port

Navigation Point

Fig. 4-6 Data Buoy Locations for the 25 Percent Buoy System (Continued)



a. Coastal North America Data Buoy Locations (56)



b. Deep Ocean Data Buoy Locations (4)

Fig. 4-9 Data Buoy Locations for the 60-Buoy System (Unconstrained)

Coast, East Coast, and the Gulf of Mexico MDZs have 15, 18, and 12 buoys respectively. These buoys are located strategically to serve oil and gas interests, commercial and sports fishing interests and, to the best extent possible, meteorological and oceanographic forecasts in coastal and inland regions and off-shore maritime regions.

4.7 System Relative Effectiveness

It was not one of the major purposes of this study to consider the effect of system size (number of buoys) and location of buoys in a system relative effectiveness framework. It was recognized, however, that location of buoys for the seven data buoy systems should be based, to the degree possible, on rationales relating buoys in various MDZs to the potential utility of the collected data and likely data products ultimately to be produced and used. At the request of the NDBS DPO, TRC undertook a very brief and highly subjective analysis of data buoy system relative effectiveness as a function of system size.

In contrast to other topics in this report which are based on objective structures of analysis and are believed to be at least as well-founded as the cost and other assumptions that underlie them, the system relative effectiveness results presented here are recognized to be completely open to dispute and obviously in need of considerable refinement. Both TRC and the NDBS DPO recognized that neither time nor resources were available to carry out a study of data buoy system relative effectiveness at the desired level of detail. Yet, it was clear to both parties that the need existed to create at least an initial "strawman" to give some insight into the complexity of relating numbers and locations of buoys to the utility and/or benefits to be derived from the collected data and commensurate data products. The subjective approach used here may serve this need somewhat by providing an initial frame of reference for discussion and some topics and ideas to stimulate further thought along these lines.

4.7.1 The Baseline System

The 500-buoy baseline system (Fig. 4-2), provides more buoys, more densely located in all MDZs than any of the other systems (minor exceptions: some transect lines that appear in the 375, 250, and 50% systems). More area is covered by the baseline system, although the "worth" to the U.S. of having buoys in the far reaches of the Northwest Pacific is by no means clear. (It must be remembered that the form

of the baseline system was primarily specified to give a reference point for the deployment study.) The baseline system is arbitrarily assigned a system effectiveness score of 100. The estimated system effectiveness for each of the six other data buoy systems is scored relative to the 500-buoy baseline system.

4.7.2 Criteria for Estimating Effectiveness Scores

The list of users of the oceans and marine environmental information has been well-documented elsewhere, especially in efforts to establish the nature of potential benefits to be derived from collection of marine data through use of buoys [5]. For this cursory effort, seven categories of economic users were used; Table 4-3 shows these categories and relative weights assigned to each. It is obvious that to be more complete, Table 4-3 should also include several military and social (general public) categories.

TABLE 4-3
RELATIVE IMPORTANCE OF ECONOMIC USES OF BUOY-COLLECTED DATA

Users	Relative importance (weights)
1. Long range forecasting	15
2. Short range forecasting	15
3. Ocean research	35
4. Oil/gas/minerals	10
5. Commercial fisheries	10
6. Recreation	5
7. Other	10
Total	100

It would be unlikely that data derived from each of the 9 northern hemisphere MDZs would all be of equal value, even to a single category of users. Therefore, a maximum attainable score was assigned to each MDZ; this score (Table 4-4) reflects personal judgment of the overall relative value of data from each MDZ.

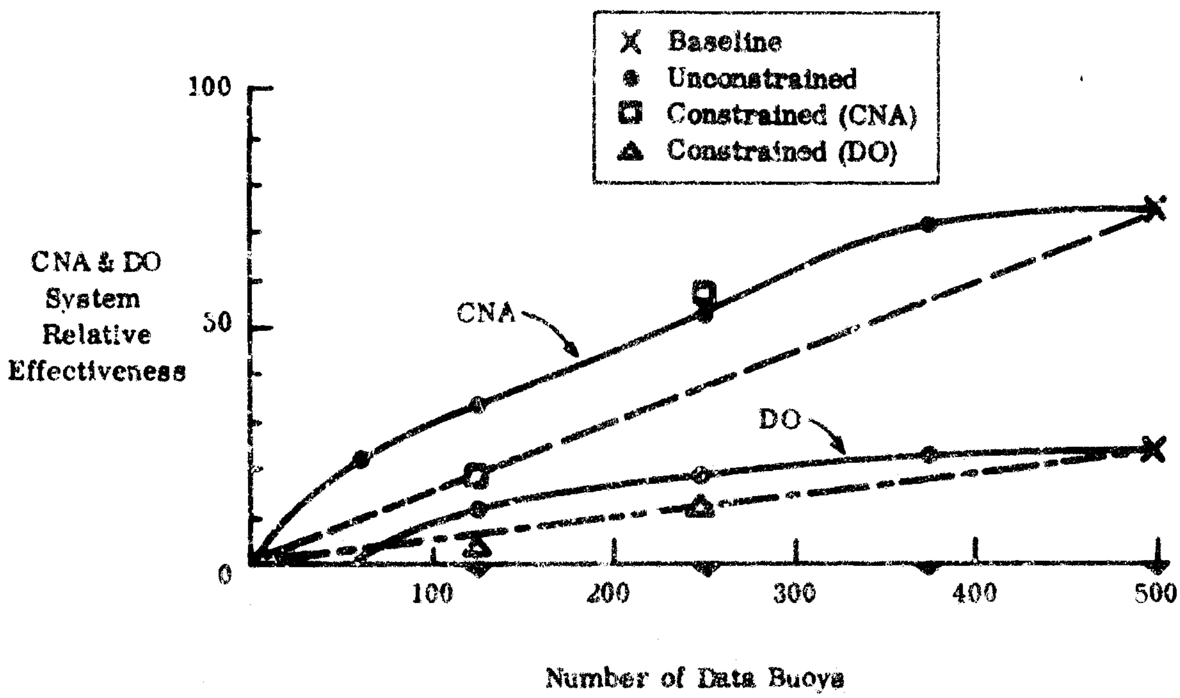
TABLE 4-4
MAXIMUM ATTAINABLE MDZ SCORES

MDZ	Maximum attainable MDZ scores
Grand Banks	8
East Coast	19
Gulf of Mexico	13
Mexican Coast	5
West Coast	18
Gulf of Alaska	12
Subtotal	75
North Pacific West	4
North Pacific East	10
North Atlantic	11
Subtotal	25
Total Score	100

4.7.3 System Relative Effectiveness Estimates

The next step in this brief exercise to determine system relative effectiveness was to prepare estimates of degree of satisfaction of each of the seven user categories for each MDZ deployment in each of seven data buoy systems. Thus, the scope of even this brief investigation involving 7 user categories, 9 MDZs and 7 systems requires 343 individual estimates.* The result of these estimates is shown in Table 4-5. Figure 4-10 illustrates in comparative fashion the system relative effectiveness estimates for the CNA and DO regions, and for all buoys in each of the seven systems. Hypothetical linear relative effectiveness curves have been shown for CNA, DO, and combined conditions.

*There are 441 elements in this 3-dimensional USER/MDZ/system matrix. But the baseline system scores 100 by assumption, and 5 MDZ/system elements are zero because of (essentially) no buoys being placed in the 64-buoy and 100-buoy systems. Therefore, there are (54 - 5 =) 49 MDZ/system elements for which estimates must be made for each of the 7 user categories.



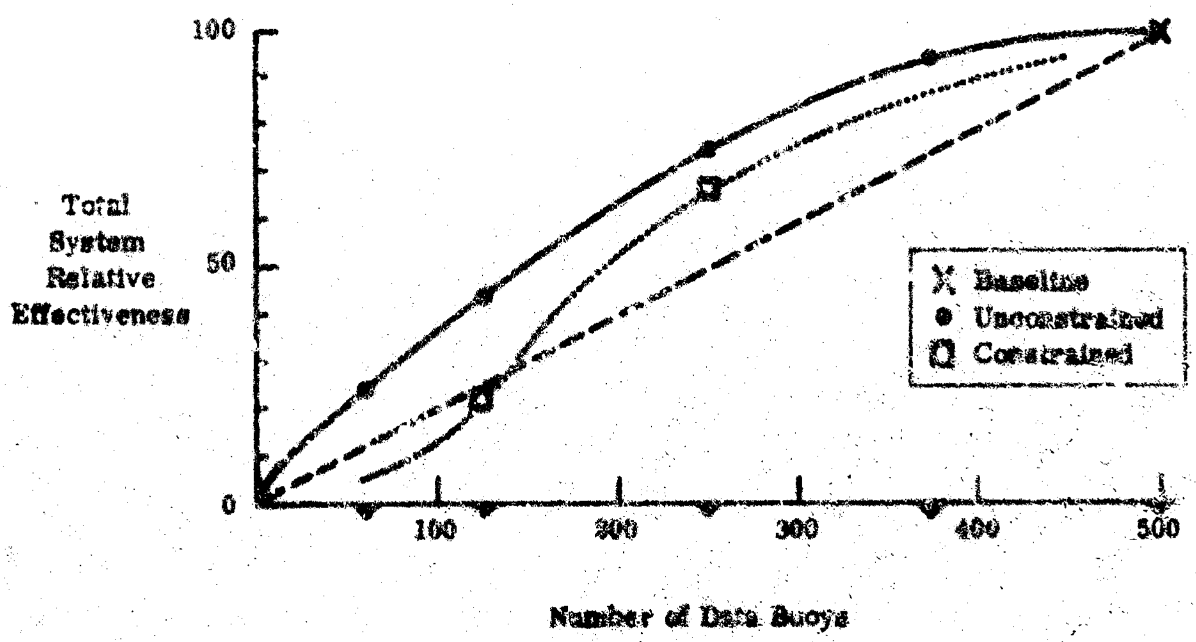


Fig. 4-10. System relative effectiveness estimates.

TABLE 4-5
ESTIMATED RELATIVE EFFECTIVENESS SCORES

MDZ	Data buoy system estimated relative effectiveness score						
	500 base-line	375	250	50%	125	25%	60
GB	8	7.6	4.8	6.4	1.6	2.8	0.8
EC	19	18.05	17.1	11.40	11.40	3.8	10.45
GM	13	12.74	8.45	9.75	5.20	2.6	3.9
MC	5	4.9	2.0	4.0	0.25	2.0	0
WC	18	16.74	13.50	15.3	9.0	4.5	4.5
GA	12	11.64	7.2	9.6	4.8	3.6	2.4
Subtotal	75	71.67	53.05	56.45	32.25	19.3	22.05
NPE	10	9.5	9.0	6.0	5.5	0.50	0
NPW	4	3.2	2.4	1.6	0	0.08	0
NA	11	10.45	8.25	3.3	5.5	1.1	0
Subtotal	25	23.15	19.65	10.9	11.0	1.68	0
Total	100	94.82	72.70	67.35	43.25	20.98	22.05

The average marginal contribution to system relative effectiveness by each additional buoy has been computed for the unconstrained deployments; it is compared with the linear marginal contribution* in Fig. 4-11. It is perhaps noteworthy that marginal system relative effectiveness decreases essentially linearly through the 375-buoy system, then falls off more sharply as the 500-buoy mark is approached.

Figures 4-10 and 4-11 give rise to some of the more obvious conclusions that can be drawn from a brief investigation such as this. The conclusions are as follows:

1. A much higher marginal system relative effectiveness can be expected from the first 250 buoys (or so) deployed.

*That is, 100 points/500 buoys gives 0.2 system relative effectiveness points per buoy added, on a linear basis.

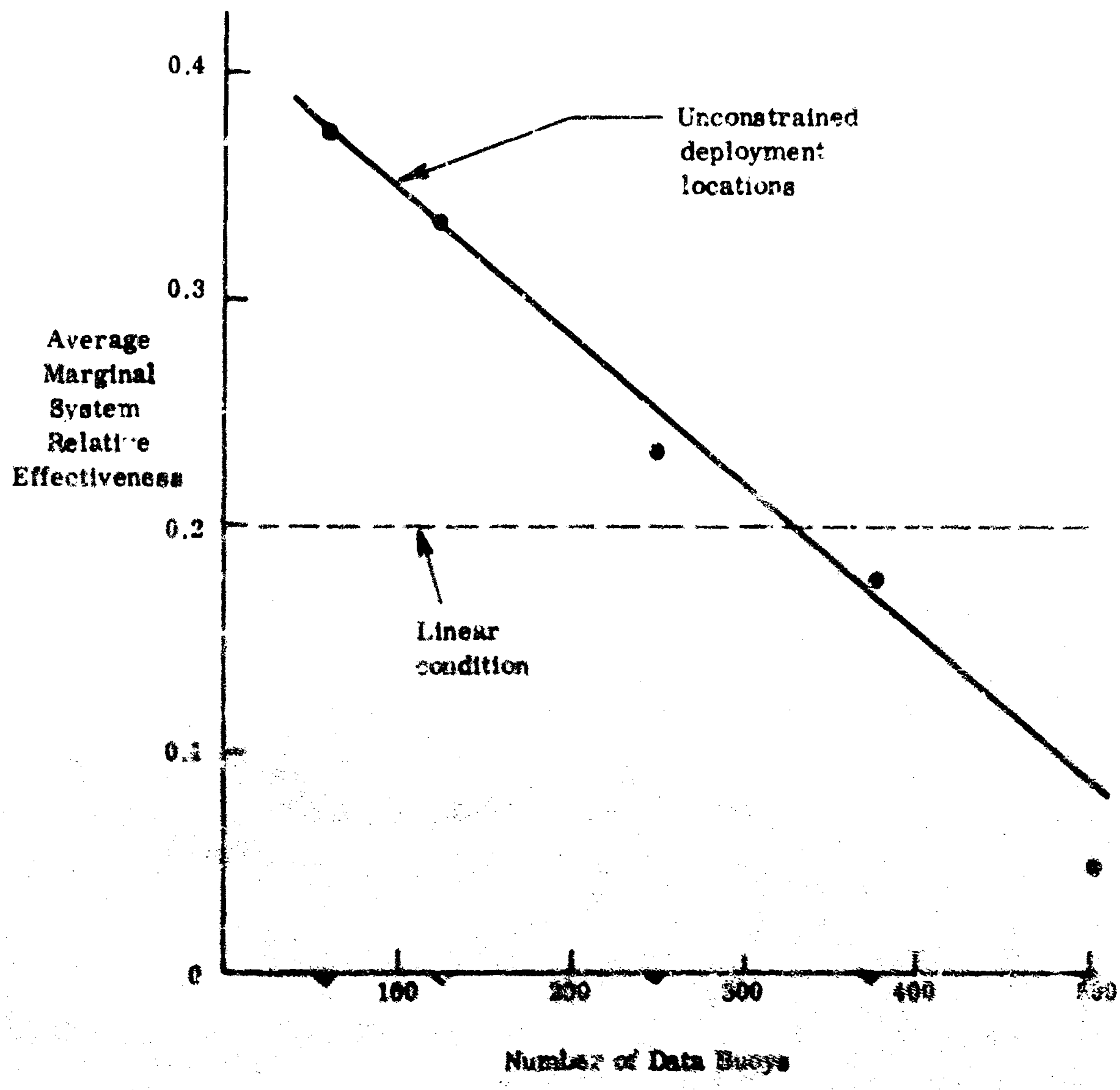


Fig. 4-11. Average marginal system relative effectiveness.

2. For data buoy systems growing in size over time, high marginal system relative effectiveness is achieved by letting the system designer select locations that best support data requirements and benefits. The alternative of building up a data system by equal evolutionary growth in all MDZs (the 50% and 25% systems) is not as effective an approach.

3. Marginal system relative effectiveness becomes low, once about 375 buoys have been deployed.

4. Compared to a hypothetical linear growth, the system relative effectiveness results for the seven buoy systems studied show that marginal system relative effectiveness peaks with the 60-buoy system, and continues relatively high through the 125-buoy (unconstrained) system. At the point of the 375-buoy system, marginal system relative effectiveness per buoy added is less than one-half the value of the 60-buoy system. Beyond the 375-buoy system, marginal system relative effectiveness is of the order of one-tenth the value for the 60-buoy system.

None of the above comments is out of line with what probably would have been grossly estimated on an intuitive basis. Yet, it must be fully recognized that agreement with intuition is insufficient to give a high level of confidence to the use of the results presented here. Indeed, this brief investigation points out all the more strongly the need to expend one to two magnitudes more effort to relate in a truly objective fashion utility of data and data products and/or benefits to numbers and locations of data buoys. It is hoped that this brief example will serve to arouse thought and interest in advancing this area of study.

4.8 Summary

In summary, it must be stressed that the principal consideration in this buoy deployment study was to locate specific numbers of buoys at reasonably representative locations throughout the northern hemisphere Deep Oceans and Coastal North America regions. To carry out this assignment, any of a number of approaches might have been chosen and, as a matter of fact, at least three rather distinct rationales have been employed. The purpose for using three alternative rationales was to determine the sensitivity of results, such as average ship operating cost per buoy planted. The locating of buoys for the various configurations used in this study should not be taken as indicative of preferred locations for NDBS data-collecting buoys. The exact locations at which buoys will ultimately be deployed will have to be chosen by the appropriate representatives of interested U.S. government agencies, in conjunction with the identified ultimate users of the data or products derived from the data. As will be seen in succeeding sections of this report, it is considered that adequately representative deployments of buoys have been investigated to provide a firm statistical base for decisions related to NDBS planning at this stage of buoy system development. As actual desired locations of buoys are determined, the buoy deployment/maintenance simulation and cost model used for this study can be used for determining explicit strategies and details associated with coordinated agency/user location choices.

5.0 ANALYSIS OF SHIP SPEEDS, BUOY-CARRYING CAPACITIES, AND COSTS

This section presents buoy deployment/maintenance simulation and cost model results that indicate "optimum" ship characteristics, based upon the set of ship characteristics and costs described in Section 3. While the results of this analysis are not sufficiently comprehensive to state categorically that for the input cost data provided the "optimum" deployment ship has been defined, it is believed that the results presented herein are sufficiently convincing to provide guidance for development planning at this time.

A number of corollary buoy system deployment features are also presented in this section. Many of these features are independent of specific input ship characteristics and/or costs. For example, in Section 5.2 the total distance traveled to deploy all buoys in each of the seven typical data buoy systems described in Section 4 is given. These results depend only on buoy deployment strategies, such as those described in Appendix B.

This section concludes with a resume of buoy hardware costs, based on equipment costs listed in Table 3-4, for a data buoy comparable to the ONR 40-ft discus. In the course of computing buoy hardware costs, it has been necessary to determine the mooring depth for each buoy in all seven data buoy systems; a total of more than 1000 depths at selected geographical points in the northern hemisphere has been used. Another output of the model that is independent of cost inputs is total length of mooring for a buoy system and/or average mooring depth per buoy by MDZ or for a total buoy system. Total buoy hardware cost, of course, is dependent upon the cost assumptions of Table 3-4 and other assumptions such as the requirement to instrument IAPSO levels down to and including depths of 5000 meters. Thus, the buoy hardware costs are presented only to illustrate what these costs might be, in the event one of the more long-lived types of data buoy is deployed.

5.1 Approach to Determination of Average Ship Operating Cost

One of the key planning factors that can be generated from a study such as this is the average ship operating costs per buoy deployed. This planning factor is a function of a large number of variables including all of those involved in Eq. 1 for total ship cruise costs (see Section 3). Average ship operating cost per buoy planted is defined to be:

$$\text{Average ship-operating cost per buoy planted} = C_{avg} = \frac{\sum_{k=1}^{K} C_k}{\sum_{k=1}^{K} N_k} \qquad \text{(Eq. 2)}$$

where C_k = Total ship cruise cost on k^{th} cruise (\$) (see Eq. 1)

N_k = No buoys deployed on k^{th} cruise

K = Total number of cruises.

The general nature of Eq. 2 is of interest because it is a function of ship buoy-carrying capacity and ship speed. Cruise deployment schedules and location of buoys and ports and ship buoy-carrying capacity determine the distance traveled for each cruise. The sum of all cruise distances in an MDZ represents the total distance traveled to deploy all buoys in the MDZ and, when summed over all pertinent MDZs, gives the total distance traveled to deploy all buoys in regions such as CNA or DO, or for all buoys in a total system. Once total deployment distance traveled is known, average ship speed can be used to compute time spent traveling, which is added to time-to-implant all buoys to determine total (minimum) cruise time. Port days per cruise is added to cruise time to give total (minimum) deployment time. Fuel cost and ship maintenance cost per sea-day depend on ship buoy-carrying capacity and ship speed. In general, ship maintenance cost per sea-day and fuel cost per n mi traveled tend to increase with both ship speed and ship buoy-carrying capacity, but in the non-linear fashion as indicated in Fig. 5-1. In contrast, the number of days spent at sea decreases linearly as a function of ship speed for given deployment schedules. In turn, that portion of cruise costs that depend on time at sea also decreases linearly as a function of ship speed. Thus, the cost curves of Fig. 5-1, which are essentially constant over the low speed range of 9 to 15 or 18 kt, and the linearly decreasing time spent at sea per cruise as ship speed increases, cause ship operating costs to decrease until ship maintenance and fuel costs begin to increase in the 15 to 18 kt region, thus causing cruise costs to pass through a point of minimum (at 15 or 18 kt for the cost curves given) and increase relatively sharply for ship speeds above 18 kt, for all ship buoy-carrying capacities. These points are illustrated in Fig. 5-2, which shows the general nature of the cost curves, the decrease in distance

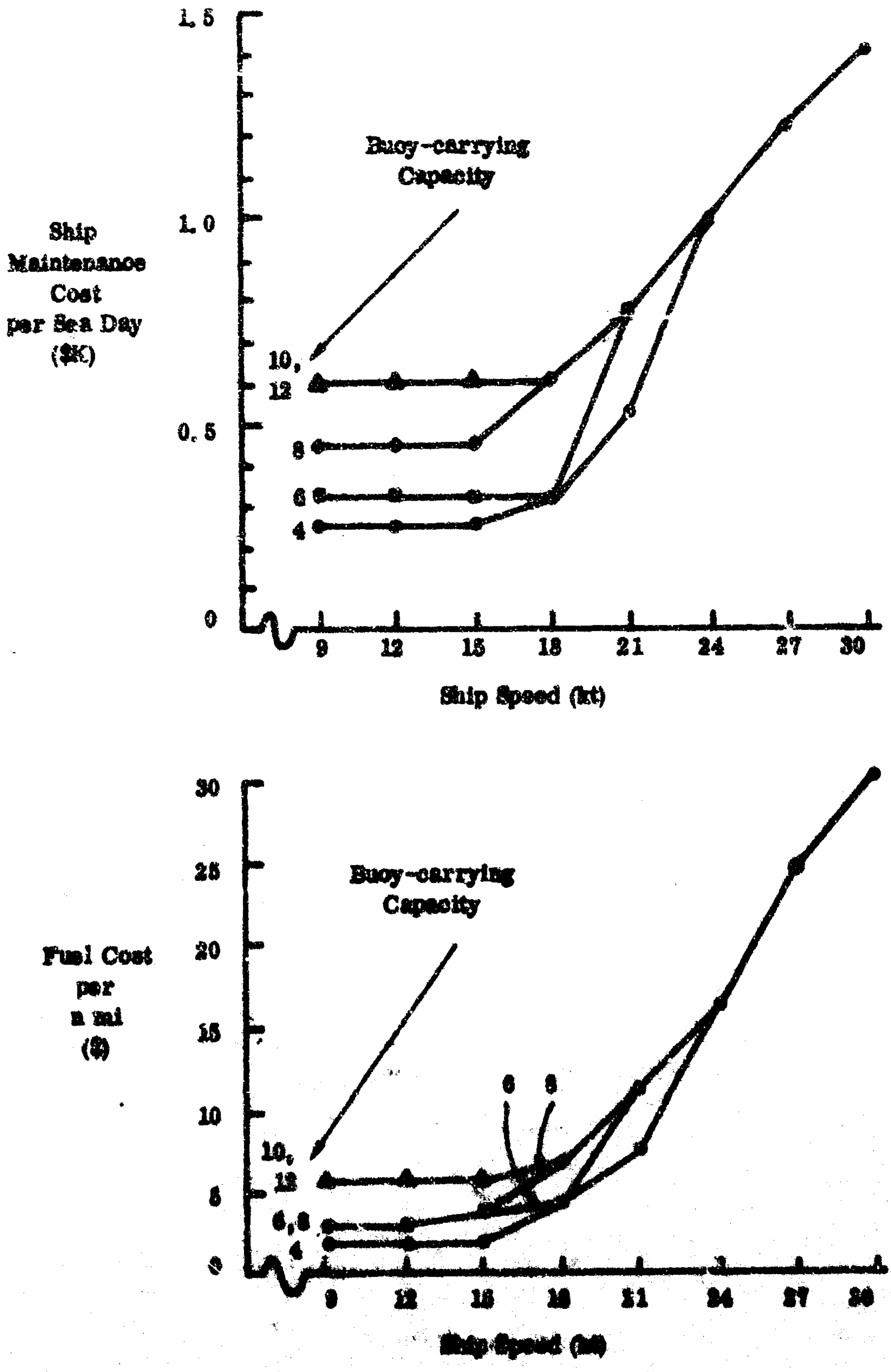


Fig. 6-1. Ship operating costs.

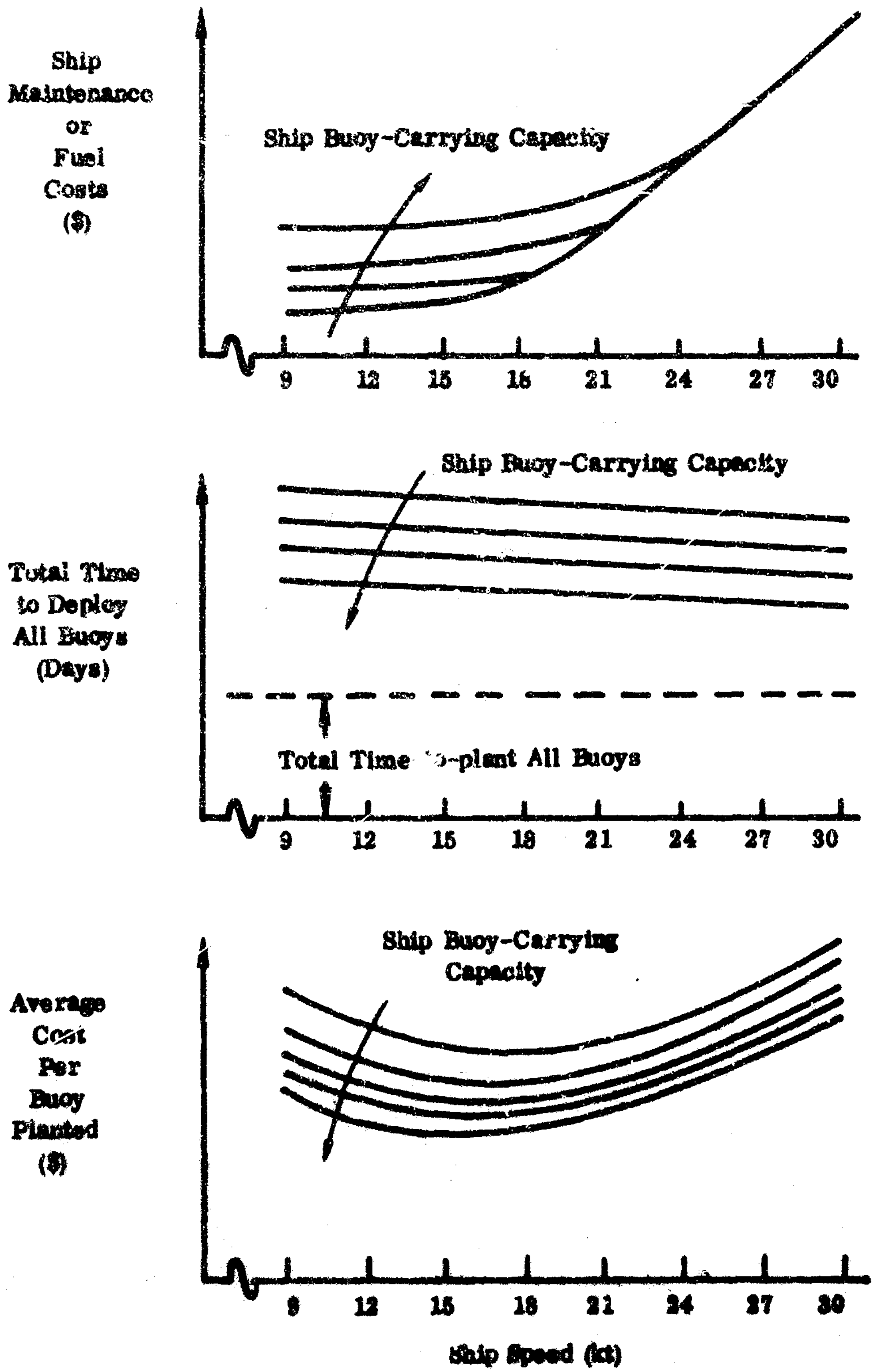


Fig. 5-2. Typical ship operating cost curves.

traveled (and hence total costs per cruise due to base costs per sea-day) and the resulting average ship operating cost per buoy-planted curves, all as a function of both ship speed and ship buoy-carrying capacity.

Of course, there are many other facets of the buoy deployment/maintenance simulation that are of interest. A number of these are shown in Table 5-1, which gives for the 500-buoy baseline system North Atlantic MDZ, cruise data for an 18 kt ship. The table illustrates that increasing buoy-carrying capacity from 4 to 12 permits essentially a 50 percent reduction in distance traveled to deploy the 48 North Atlantic buoys (using the 8-buoy ship affords a 41 per cent reduction in distance traveled for this MDZ). Of course, this reduction in distance traveled is a direct function of the number of cruises required; these range from 12 cruises for the 4-buoy ship to 4 for the 12-buoy ship. Using a safety factor of 1.0, total minimum deployment time can be determined; it varies from 331 to 168 days for the 4-buoy and 12-buoy ship respectively. The amount of time in port and at sea is also indicated. For the 4-buoy ship, over 50 per cent of the time is spent in port; for the 12-buoy ship, only 34 per cent of the

TABLE 5-1
500-BUOY BASELINE SYSTEM
NORTH ATLANTIC MDZ CRUISE DATA: 18 KT SHIP SPEED

Number cruises required	Total min deployment time (days)	Time in port (days)	Time at sea (days)	Max cruise length (days)	Avg. cruise length (days)	Avg. days per buoy planted	Max No. buoys planted per ship year
12	331	120	211	23	17.6	6.9	49
8	245	80	165	25.6	20.6	5.1	66
6	205	60	145	28.5	24.2	4.3	79
5	183	50	133	30.7	26.6	3.8	88
4	168	40	128	35.1	32.0	3.5	96

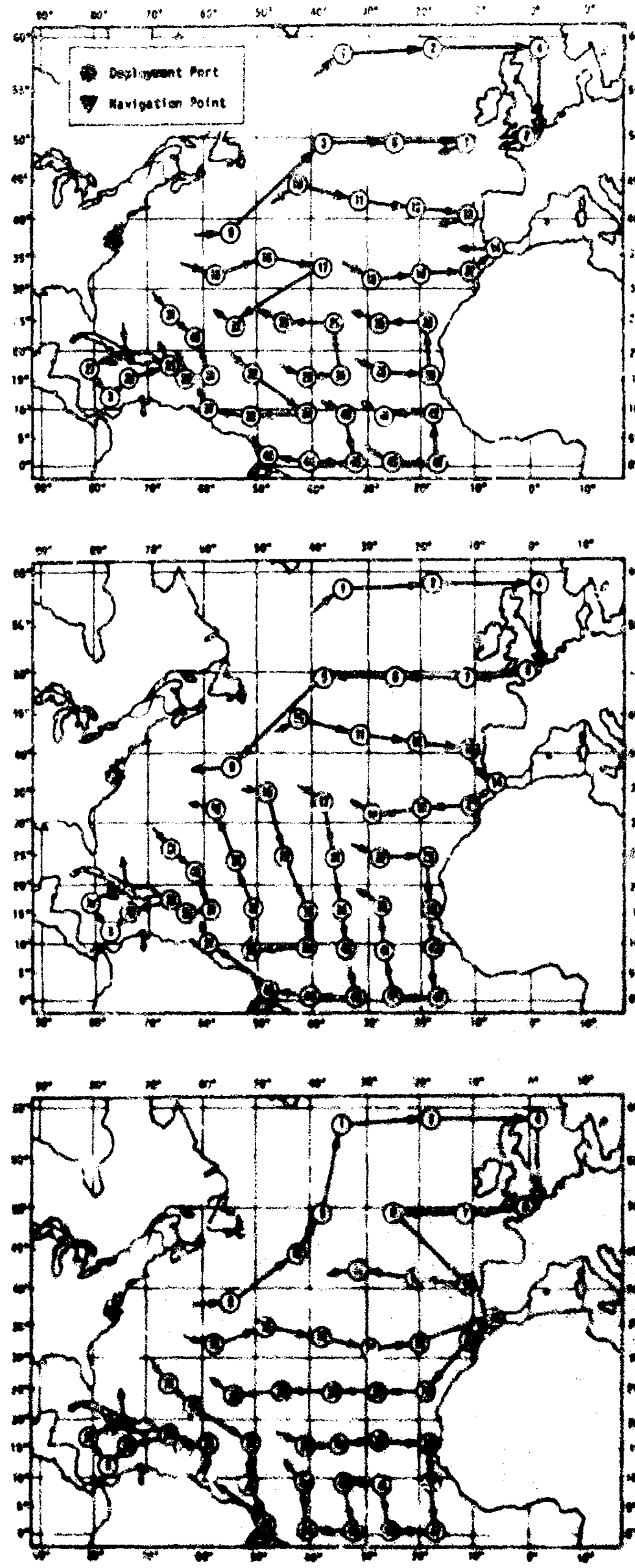
Notes: (1) Time-to-plant = 24 hr (4) Port days/cruise = 10
(2) Base cost/sea day = $5000 (5) Ship speed = 18 kt
(3) Safety factor = 1.0 (6) Days/ship year = 335

deployment time is spent in port. It is clear, however, that use of the 12-buoy ship, loaded to its maximum capacity, will require average deployment cruise times of 35 days, minimum. (This factor depends in part on the assumption of 24 hours time-to-plant for each buoy.) Because a safety factor of 1.0 has been used, it must be recognized that actual cruises could be longer in time than these figures indicate. Such lengthy cruises may be bad for crew morale. (Of course, only four such cruises would be required to deploy all 48 North Atlantic MDZ buoys.) Finally, the table shows two important planning factors that can be obtained from the previously listed data; namely the average number of days required per buoy planted and the maximum number of buoys that could be planted per ship-year (based on 335 days per ship-year).

The TRC buoy deployment/maintenance simulation and cost model provides data shown in Table 5-1, as well as other useful information (see Appendix A). This type of data has been generated and analyzed for each of the seven buoy systems outlined in Section 4. In general, in this section, specific results of analyzed data will be presented for the 500-buoy baseline system. Comparable results have been obtained for the other buoy systems but the results proved to be linearly dependent on number of buoys in the system; therefore, for the most part, only average values and total results are compared for all seven systems. It will become apparent, as the presentation of material in this section proceeds, that the average values presented (the "planning factors") are essentially independent of the number of buoys in the systems, once systems of approximately 100 or so buoys are taken under consideration.

5.2 Total Distance Traveled to Deploy

As discussed in the previous section, total distance traveled to deploy data buoys is one of the key factors in determining average ship operating cost per buoy planted, and is intrinsically independent of cost assumptions. It is, of course, completely dependent on the choice of buoy and port locations and the cruise schedules relating them. A detailed discussion of preferred cruise scheduling is given in Appendix B. Figure 5-3 shows three typical cruise deployment schedules for the 500-buoy baseline system North Atlantic MDZ, where there are 48 buoys to be deployed;



a) Cruise schedule for deployment by 4-buoy ship

b) Cruise schedule for deployment by 8-buoy ship

c) Cruise schedule for deployment by 12-buoy ship

Fig. 5-3. Deployment cruises for the North Atlantic 500-buoy baseline system.

the figure shows cruise schedules for 4-buoy, 8-buoy, and 12-buoy deployments.*

Figure 5-4 shows total distance traveled for the East Coast MDZ and the North Atlantic MDZ; average distance traveled per buoy planted is also indicated on each figure. Note that for the 12-buoy ship it is necessary to travel a little over 700 n mi per buoy deployed in the North Atlantic MDZ, but only about 150 n mi per buoy planted in the East Coast MDZ, thus illustrating the difference in distance traveled in planting CNA and DO data buoys, a ratio of almost 5 to 1 in this instance. (It should be held in mind that for the 500-buoy baseline system there are 350 CNA data buoys and 150 DO buoys, or a ratio of 2.33 to 1.0. This ratio was held constant for the 50 per cent and 25 per cent of baseline systems. It was varied somewhat for the 375, 250, 125, and 60-buoy systems.)

Considering all seven data buoy systems, Fig. 5-5 gives total distance traveled to plant CNA buoys, DO buoys, and the combination of DO and CNA buoys. Note that the distances traveled for the 50 per cent and 25 per cent systems are somewhat greater than for the comparable 250 and 125 buoy systems. The primary reason for this is that more buoys were deployed in the North Pacific West MDZ and the Mexican Coast MDZ in the 50 per cent and 25 per cent systems. With these exceptions, total distance traveled tends to be a monotonically (approximately linear) decreasing function of the number of buoys in the system, as would be expected.

Total distance traveled to plant all buoys varies from 200,000 n mi for the 12-buoy ship deploying the 500-buoy system, to about 50,000 n mi for implanting the 125-buoy and 25 per cent systems. Figure 5-6 shows the average distance traveled per buoy planted for all seven buoy systems. The CNA, DO and combined CNA and DO regions are shown separately with curves for 4, 8, and 12 buoys per ship. These figures show the independence of average distance traveled per buoy planted as a function of system size, at least through the 125-buoy and 25 per cent system. For

* The interested reader may wish to challenge the deployment schedules shown in Fig. 5-3. As noted in Appendix B and elsewhere, no suggestion is made in this report that optimum cruise scheduling has been attained. However, Appendix B shows that certain cruise scheduling strategies are preferred over others and these guidelines have been followed throughout the study.

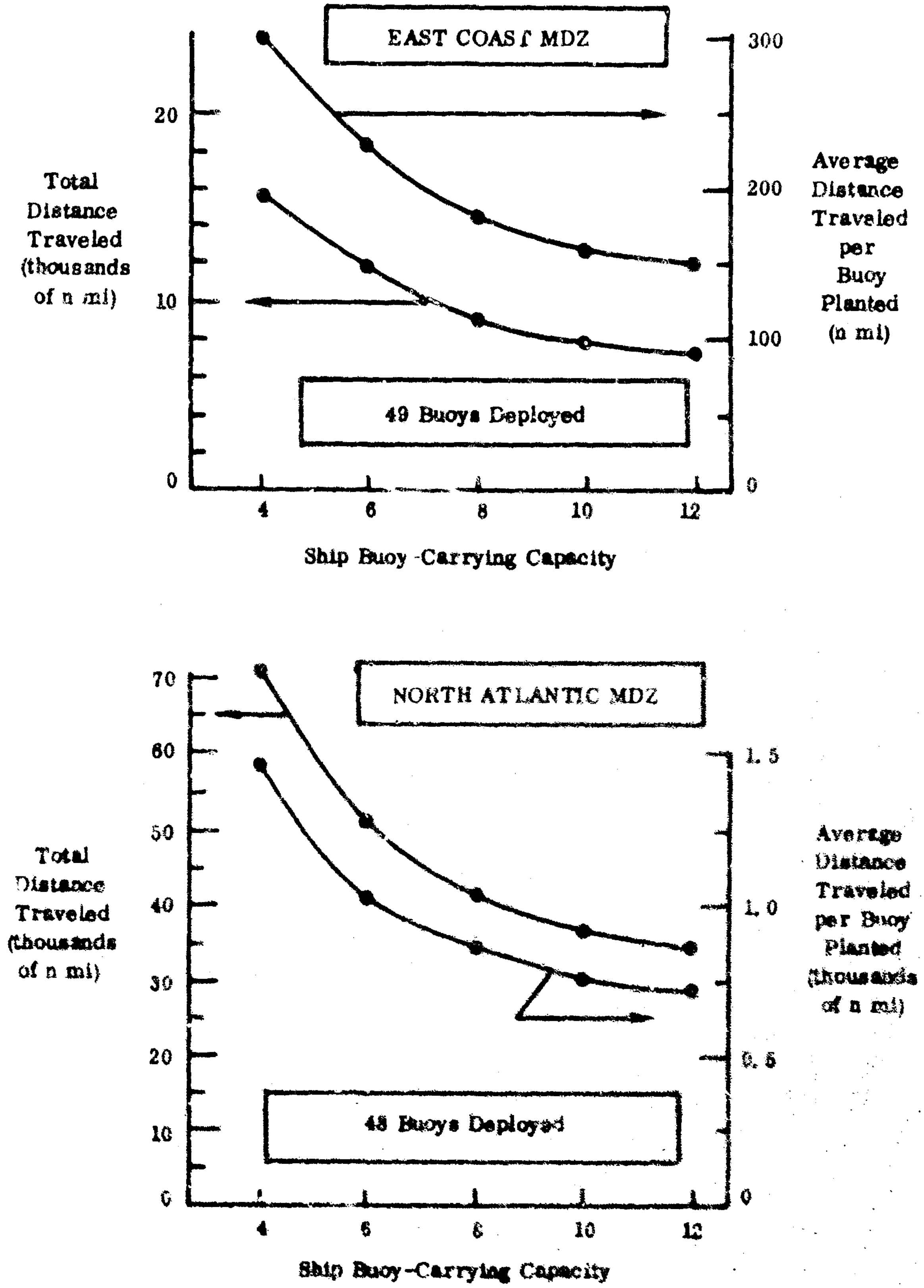


Fig. 5-4. Distance traveled to deploy buoys.

Notes: 1. Time to P'ant = 24 hr
2. Base cost/seaday = $5000
3. Safety Factor = 1.0
4. Port Days/cruise = 10

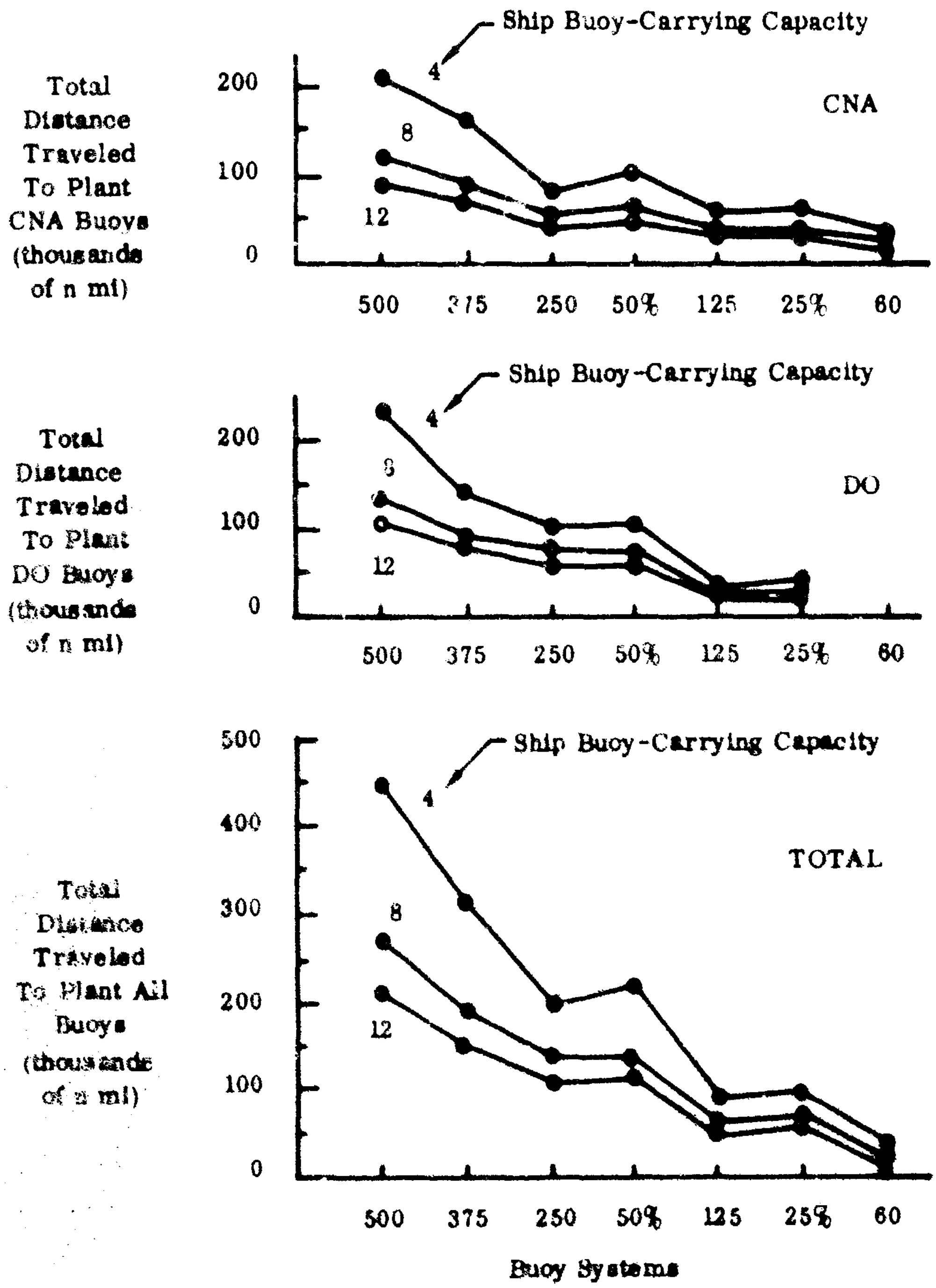


Fig. 5-5. Total distance traveled.

Notes: 1. Time-to-Plant = 24 hr
2. Base Cost/Sea Day = $5000
3. Safety Factor = 1.0
4. Port Days/Cruise = 10

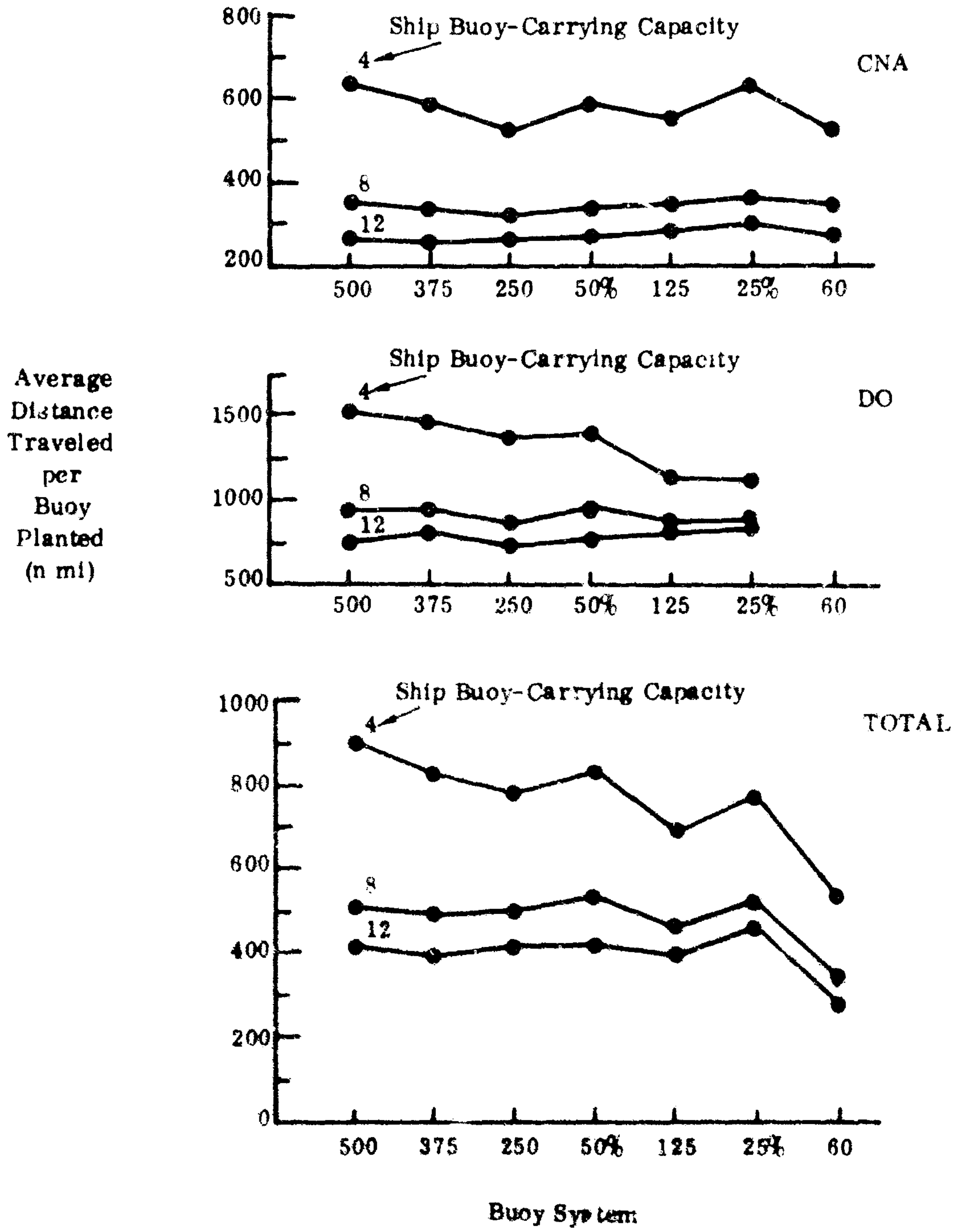


Fig. 5-6. Average distance traveled per buoy planted.

example, for the 12-buoy ship, it is clear that for all CNA MDZs (and two deployment ports) the average distance traveled per buoy planted is approximately 275 n mi. In the Deep Ocean (again, for two Deep Ocean deployment ports) the average distance traveled per buoy planted using the 12-buoy ship is about 750 n mi. Averaged over the entire northern hemisphere, the 12-buoy ship can carry out deployments at a rate of approximately 400 n mi traveled per buoy planted.

In each MDZ, there is always one cruise greater in distance traveled than any of the others. In general, this cruise depends more on the buoy that is at the farthest distance from the deployment port than it does on ship buoy-carrying capacity. This point is clearly illustrated in Fig. 5-7, which shows for the 500-buoy baseline system, maximum cruise distance in each of the nine MDZs, and indicates that ship buoy-carrying capacity has little effect on this factor. (As would be expected, increasing ship buoy-carrying capacity does increase maximum cruise distance somewhat.)

5.3 Average Ship Operating Cost per Buoy Planted

Section 5.1 has given a general explanation of how average ship operating cost per buoy planted is obtained and what the nature of the curves as functions of ship buoy-carrying capacity and speed are expected to be. Section 5.2 has shown the characteristics of one of the major factors determining average ship operating cost per buoy planted, namely, total distance traveled to deploy all buoys (in an MDZ or in CNA or DO or in the northern hemisphere), and average distance traveled per buoy planted in various MDZs or regions.

Figure 5-8 shows two sets of curves for average ship operating cost per buoy planted as functions of ship speed and buoy-carrying capacity. The data for Fig. 5-8 is given in Table 5-3. Average ship operating costs for the 500-buoy baseline system East Coast and North Atlantic MDZs are presented as representative of higher and lower average costs to be encountered for the conditions stipulated on the figure. Clearly, the minima occur at either 15 or 18 kt for each ship buoy-carrying capacity, and increasing ship buoy-carrying capacity tends to make deployment more efficient.*

*There is, of course, an upper bound on how far ship buoy-carrying capacity should be carried. That bound depends primarily on the desired maximum cruise time. The USCG NDBS DPO provided TRC with the guidance that 22.5 days at a safety factor of 1.0 represents desirable maximum cruise time. This 22.5 day factor will be discussed at a number of points in the remaining portions of this report.

Notes: 1. No. Buoys Deployed = 500
2. Deployment Ports: a. Portsmouth, Va.
b. San Francisco, Cal.
c. Honolulu, Hawaii

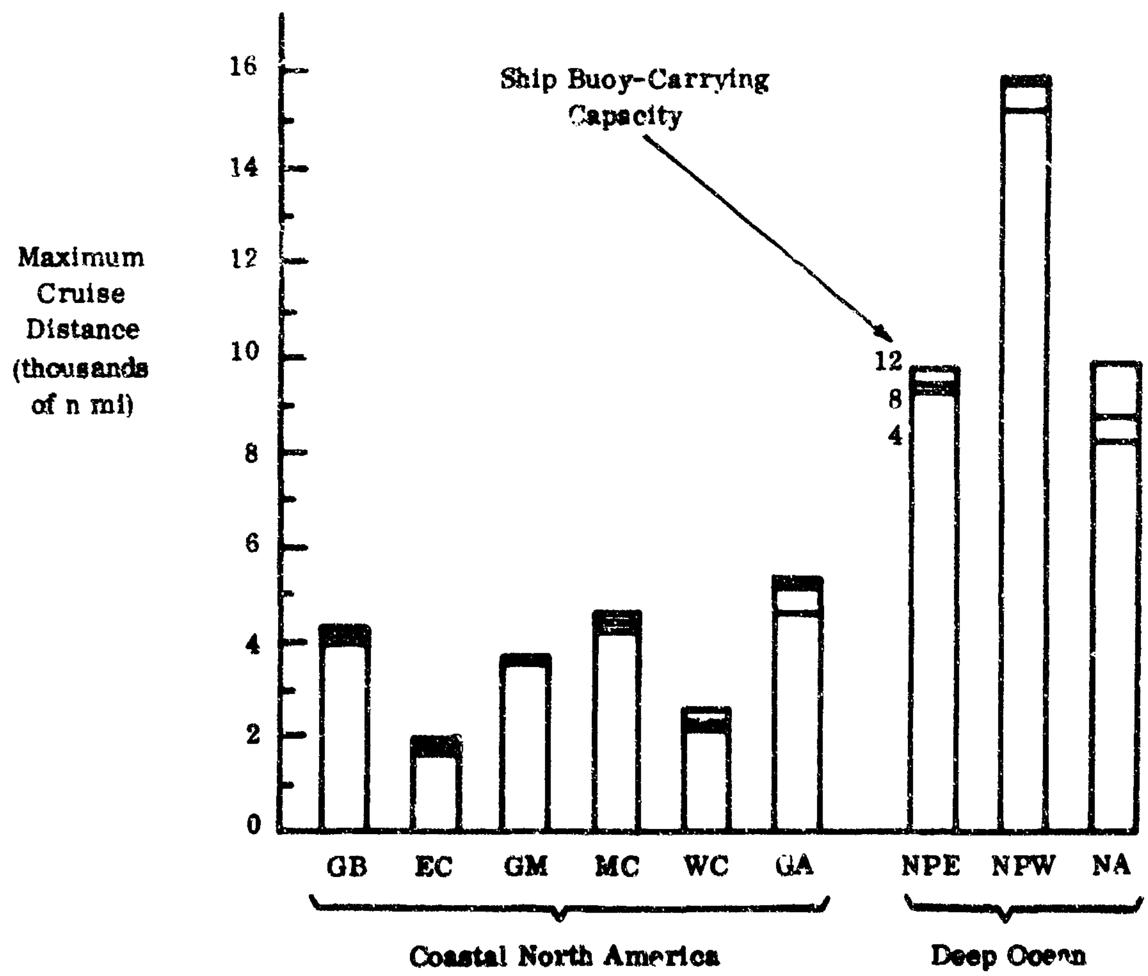


Fig. 5-7. Maximum cruise distance for each modular deployment zone.

Notes:		
1.	Time-to-Plant	= 24 hr
2.	Base Cost/Sea Day	= $5,000
3.	Safety Factor	= 1.0
4.	Port Days/Cruise	= 10
5.	Ship Speed	= 15 or 18 kt

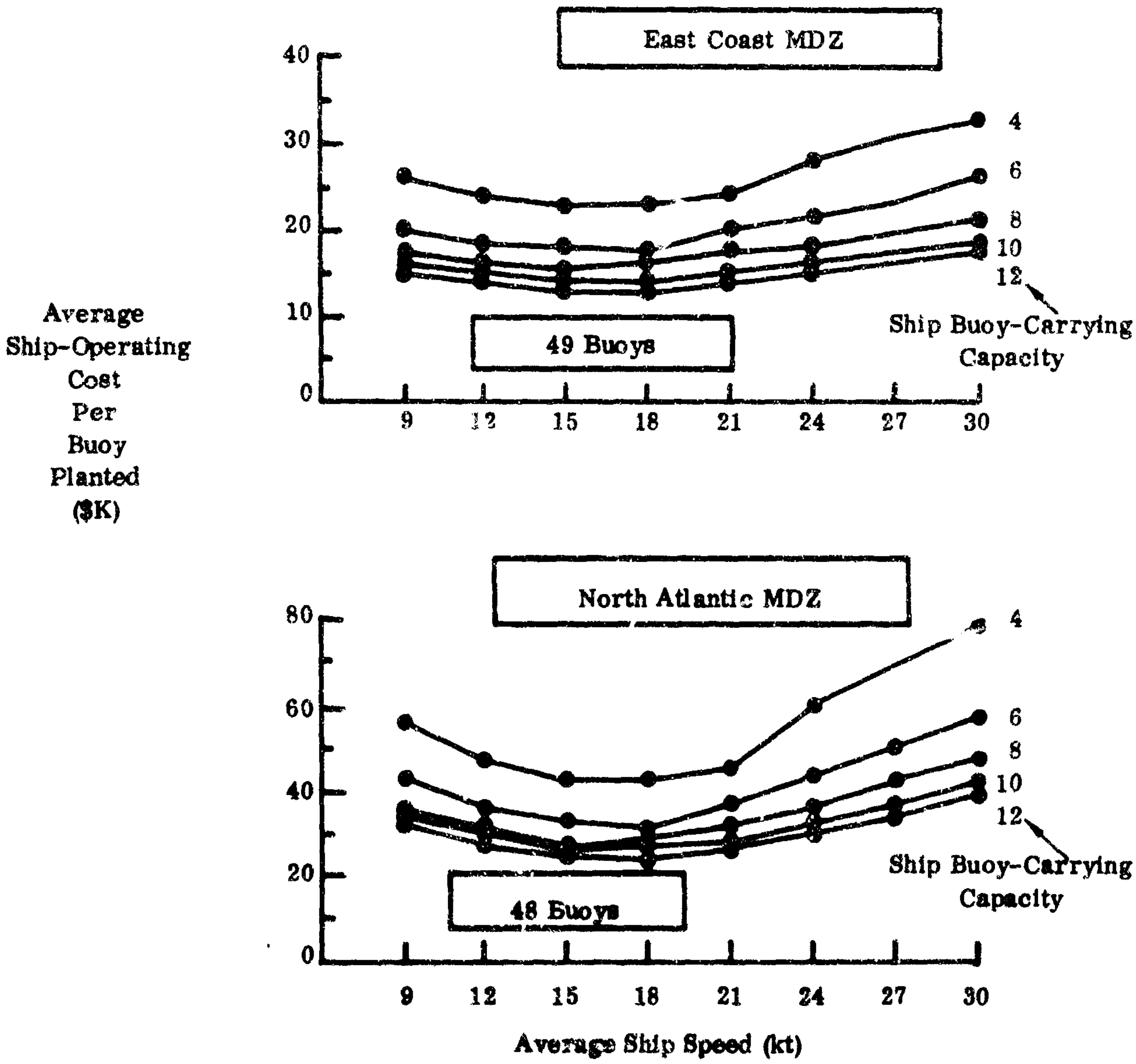


Fig. 5-8. Average ship-operating cost per buoy planted.

One aspect of the analysis for this buoy deployment study was determination of the point (or points) of minimum (or slope reversal) in the curves for average ship operating costs per buoy planted as defined by Eq. 2. In every case investigated in this study, the minimum point occurred either at 15 or 18 kt ship speed. Review of the cost curves (Fig. 5-1) indicates why this occurs. With no exception, for all cases investigated and all variations of parameters, the 12-buoy, 18 kt ship provided the lowest average ship operating cost per buoy planted. It was, therefore, decided to present most of the comparative data at ship speeds of 15 or 18 kt, commensurate with minima as a function of ship buoy-carrying capacity. Figure 5-9 is such a graph. It shows average ship operating cost per buoy planted at the points of minima on the cost curves for all nine MDZs in the 500-buoy baseline system. Average costs for ship

TABLE 5-2
500-BUOY BASELINE SYSTEM

Ship buoy-carrying capacity	Ship Speed (kt)								No. buoys deployed in MDZ
	9	12	15	18	21	24	27	30	
East Coast MDZ									
4	25.9	24.1	23.0	23.1	24.4	28.5	31.1	33.5	53
6	20.0	18.6	18.0	17.6	20.2	21.6	23.6	25.5	53
8	17.3	16.2	15.7	16.2	17.1	18.3	19.9	21.5	49
10	16.2	15.1	14.5	14.2	15.1	16.1	17.5	18.9	49
12	15.2	14.2	13.6	13.4	14.2	15.1	16.5	17.7	49
North Atlantic MDZ									
	9	12	15	18	21	24	27	30	
4	56.5	47.6	42.3	42.3	45.6	59.5	69.2	78.6	48
6	42.3	35.9	33.0	31.1	38.7	43.5	50.5	57.3	48
8	36.1	30.7	[illegible]	29.5	32.3	36.3	42.1	47.7	48
10	35.2	30.3	27.3	26.3	28.7	32.2	37.3	42.2	48
12	32.8	28.1	25.3	24.4	26.7	30.0	34.8	39.4	48

Notes:	1.	Time-to-plant = 24 hr
	2.	Base Cost/Sea Day = $5000
	3.	Safety Factor = 1.0
	4.	Port Days/Cruise = 10
	5.	Ship Speed = 15 or 18 kt

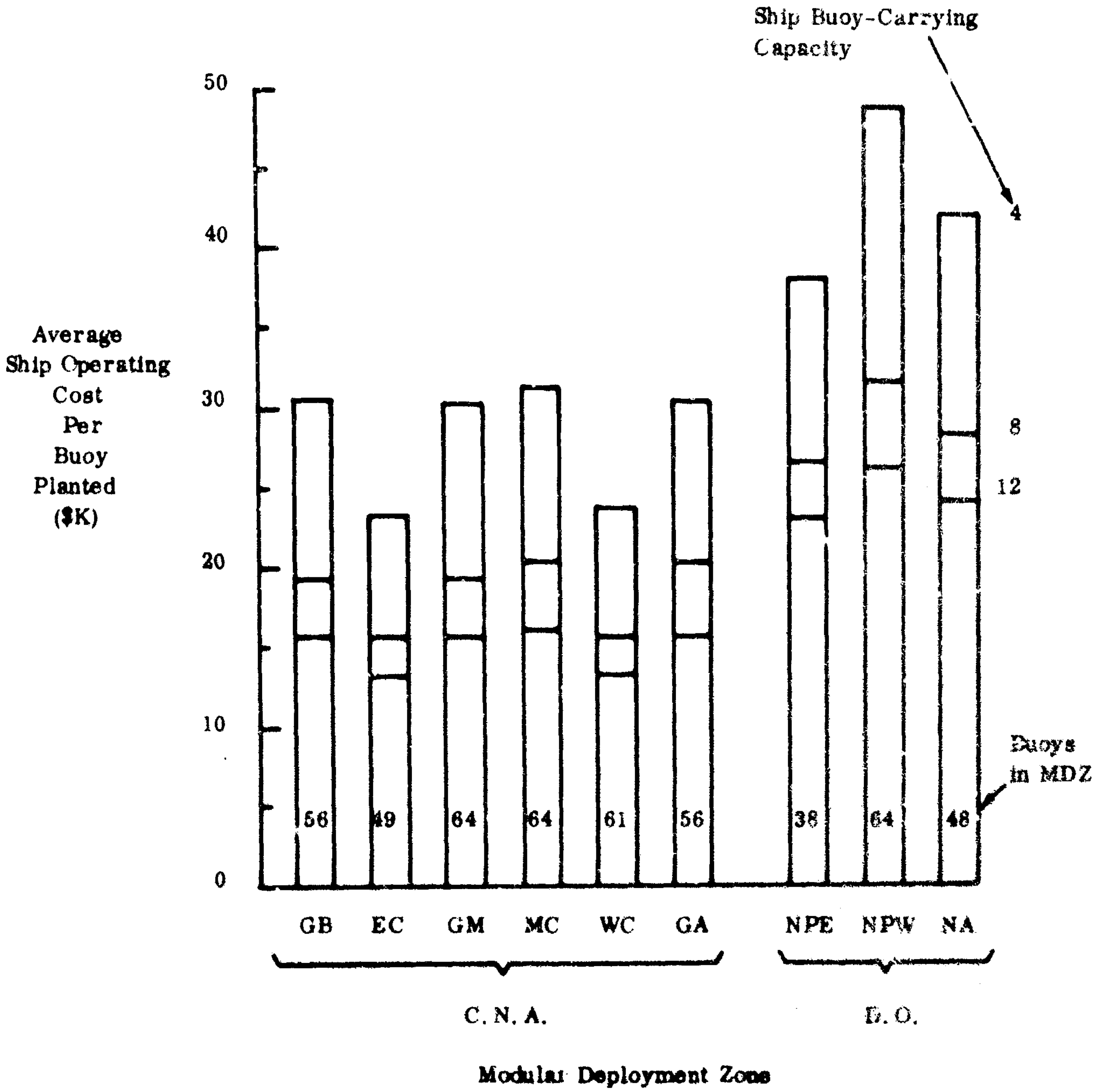


Fig. 5-9 Average ship-operating cost per buoy planted ~ baseline system.

buoy-carrying capacity of 4, 8, and 12 buoys are clearly indicated on the bar graphs.* Data was produced for 6 buoy and 10-buoy ships, but has been omitted in the interest of simplicity. Figure 5-9 makes clear the advantage of deploying buoys from deployment ports contiguous with the deployment zone. For example, average costs to deploy each buoy are lowest in the East Coast and West Coast CNA MDZs and in the North Pacific East DO MDZ, because average distance traveled to deploy buoys was lowest in these three MDZs.

Figure 5-10 shows average cost to deploy all CNA buoys for all seven systems, using ship buoy-carrying capacities of 8 and 12 buoys. The average cost is bounded by the maximum average cost found in any of the appropriate MDZs and the minimum average cost per MDZ encountered in each of the seven systems.† Also, the 8-buoy per ship and 12-buoy per ship averages are compared directly at the bottom of Fig. 5-10.

The large increase in maximum average cost per buoy planted for the 250-buoy system occurs because the number of buoys in the Mexican Coast MDZ was reduced to a small number, but of these several were located at large distances from the deployment port in San Francisco. Thus, there are no "short" buoys to counterbalance the "long" buoys. Note that the overall average for the CNA buoys in the 250-buoy system is less than the CNA buoys in the 50 per cent system. CNA average cost per buoy planted is of the order of $19,000 for the 8-buoy ship and $16,000 for the 12-buoy ship. Clearly, there is a differential of approximately $3000 per buoy planted between the average cost curves for the 8-buoy and 12-buoy ships. Thus, using an 8-buoy ship, rather than a 12-buoy ship, to deploy CNA buoys would increase average ship operating cost per buoy planted by nearly 19 per cent. For the 350 CNA buoys in the baseline system, this would amount to an increased deployment cost of $1.05 million. Recurring

* The number of buoys deployed in each MDZ does not exactly agree with the data in Table 4-2, because sometimes for efficiency of cruise scheduling, buoys from an adjacent MDZ were deployed under a different MDZ heading.

† In other words, under no conditions investigated was average ship operating cost per buoy per MDZ more or less than the curves of maximum and minimum. These curves are, therefore, useful in determining how much deviation might be expected around the average value curve, in a relative sense. Absolute values are, of course, completely dependent on the safety factor, costs, ship characteristics, and port-days per cruise assumptions.

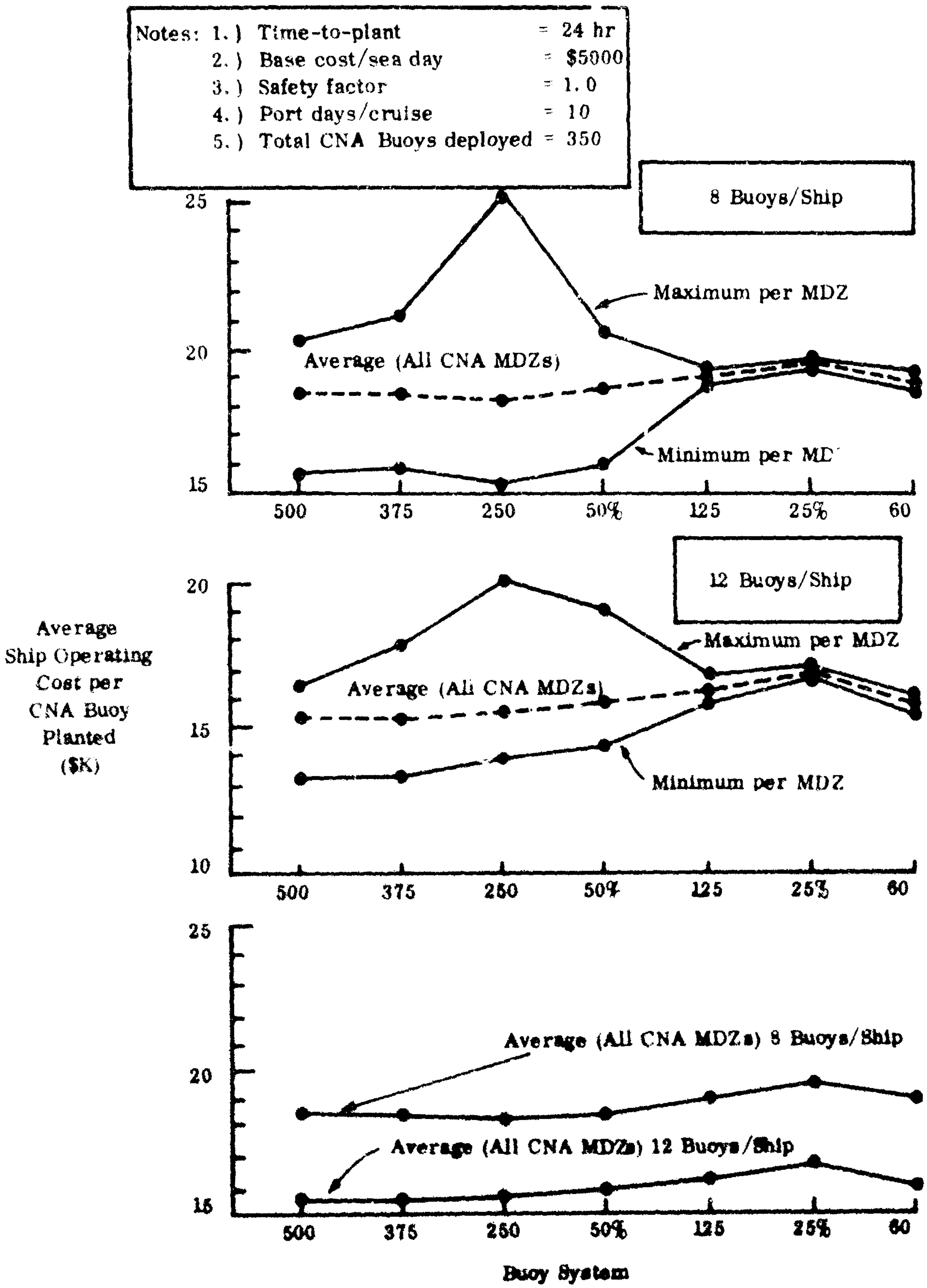


Fig. 5-10. Average ship operating cost per Coastal North America buoy planted.

maintenance costs of comparable magnitude would also occur at least annually.

Figure 5-11 shows average ship operating costs per buoy planted for the three Deep Ocean MDZs for all buoy systems, with maximum average cost per MDZ and minimum average cost per MDZ also indicated. For the buoy systems of large size investigated, use of the 12-buoy ship provides an average cost per buoy planted in the DO of approximately $25,500, while the 8-buoy ship provides an average cost per buoy planted of approximately $29,500, thus affording a $4000 differential between the two buoy-carrying capacities.

Carrying out the averaging processes over all buoys (CNA plus DO) in each of the seven systems for the 8-buoy and 12-buoy ships gives the average cost curves shown in Fig. 5-12. In this figure the grand average for all buoys is shown compared to the average for all Deep Ocean MDZs (which generally is about $7000 per buoy more) and the average for all CNA MDZs (generally more than $4000 per buoy less). Use of the 8-buoy ship produces an average ship operating cost per buoy planted of approximately $22,000 while the 12-buoy ship deploys buoys at an average ship operating cost per buoy planted of about $19,000.

Figure 5-12 makes evident the contention that average ship operating cost per buoy planted is essentially independent of number of buoys in the system. It also clearly indicates the expected result that the greater the distance from the deployment port, the more expensive it is to deploy buoys is substantiated. On the basis of average distance traveled to deploy buoys, the relationship is reversed. For example, with a 12-buoy ship, it requires about 750 n mi of travel (average per buoy) to deploy DO buoys at an average ship operating cost of $29,500 per buoy, or nearly $40 per n mi traveled. To deploy CNA buoys, the average distance traveled per buoy planted is about 280 n mi, and the average ship operating cost per buoy planted is about $15,500; this results in a cost of about $55 per n mi traveled. Planning factors such as these are useful for first estimates in determining deployment cost, given the numbers and locations of desired data buoy networks and potential deployment ports. The sensitivity of these planning factors to variations in base cost per sea-day and time-to-plant each buoy are discussed below in this section. Cost sensitivity to use of additional deployment ports is given in Section 6. Sensitivity to variation of port-days per cruise is given in Section 7. Total deployment cost is discussed next.

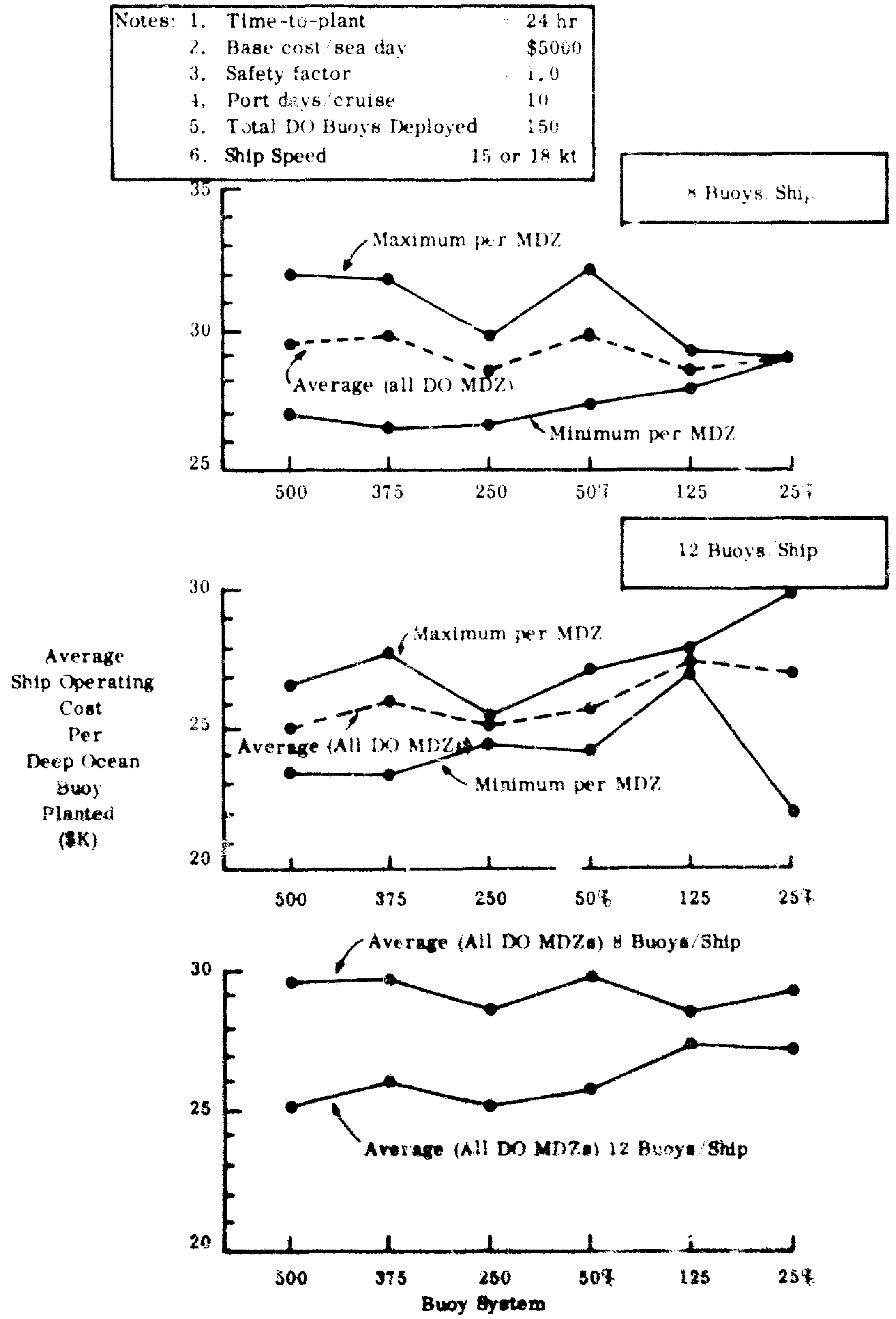


Fig. 5-11. Average ship operating cost per Deep Ocean buoy planted.

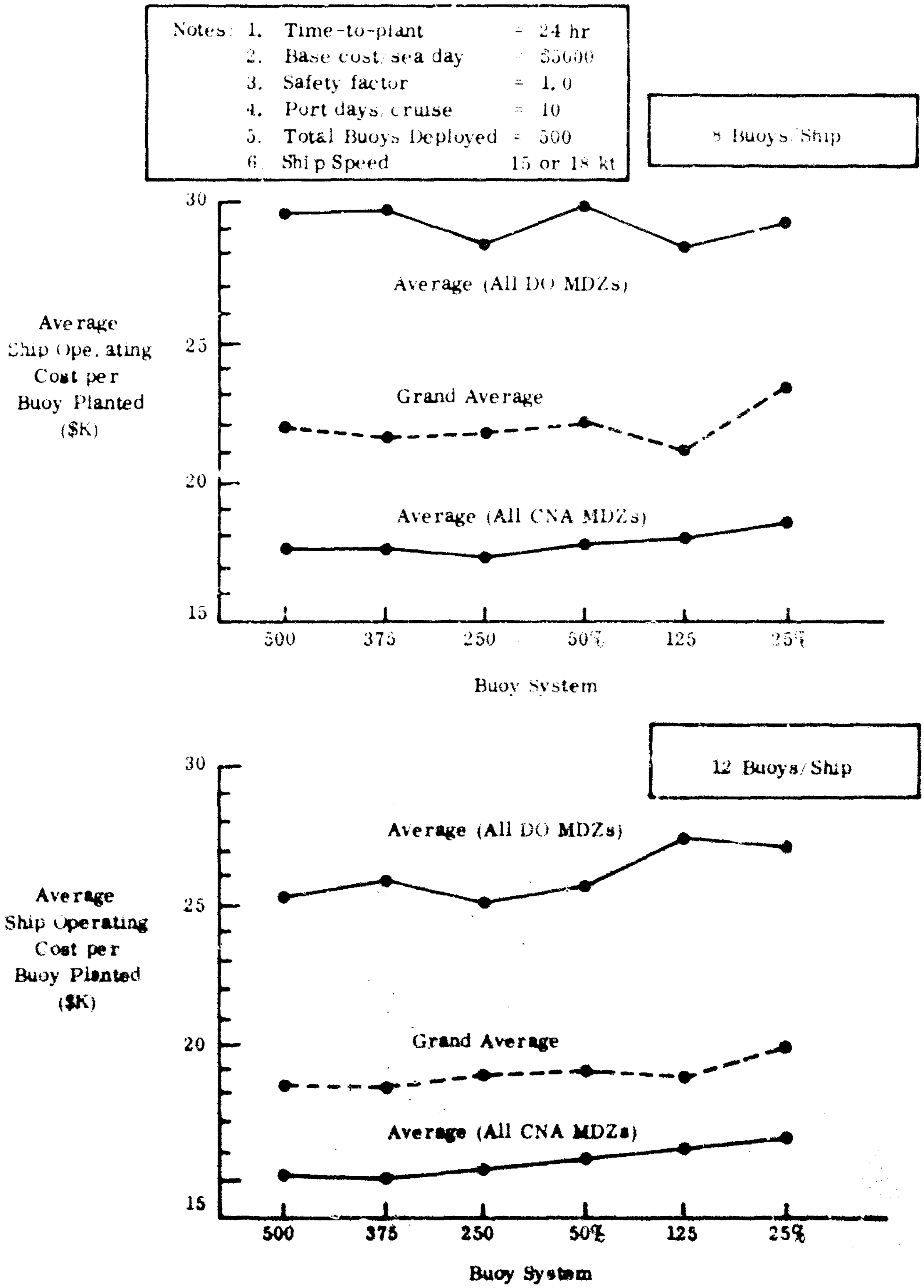


Fig. 5-12. Average ship operating cost per buoy planted.

5.4 Total Ship Operating Cost for Seven Buoy Systems

Total ship operating costs to deploy CNA, DO, and combined CNA and DO buoy systems are shown for all seven buoy systems and 4, 8, and 12 ship buoy-carrying capacities in Fig. 5-13. These total ship operating costs decrease approximately linearly with total number of buoys, as might be expected. As an overall average, the 50 per cent buoy system costs slightly more than the 250-buoy system; the same comment applies to the 25 per cent versus 125-buoy system. This occurs, of course, primarily because the 50 and 25 per cent systems have proportionately more buoys in the North Pacific West and Mexican Coast MDZs than do their 250-buoy and 125-buoy counterparts, as noted previously. The 500-buoy system deployed by a ship with a 12-buoy-carrying capacity requires slightly more than $9 million for deployment, based on a safety factor of 1.0; a time-to-plant of 24 hours; 10 port-days per cruise; $5,000 base cost per sea-day; and an 18 kt ship. This is approximately 44 per cent less than the equivalent cost of $17.4 million for a 4-buoy ship. Comparable savings are indicated throughout the 250 and 50 per cent systems with somewhat lower percentage of saving accrued in going from the 4-buoy to the 12-buoy ship for systems with less than 250 buoys. The details of ship operating cost to deploy the seven buoy systems are given in Table 5-3.

TABLE 5-3
SHIP OPERATING COST TO DEPLOY BUOY SYSTEMS ($M)

Region	Ship buoy-carrying capacity	Buoy systems						
		500	375	250	50%	125	25%	60
CNA	4	9.864	7.603	4.456	4.857	2.676	2.515	1.587
	8	6.530	5.096	3.069	3.257	1.859	1.717	1.212
	12	5.354	4.199	2.578	2.770	1.586	1.461	0.944
DO	4	6.541	4.210	3.341	3.093	1.029	1.387	
	8	4.425	2.973	2.366	2.234	0.769	1.079	
	12	3.767	2.594	2.077	1.959	0.742	1.005	
Combined CNA and DO	4	16.405	11.813	7.797	7.950	3.705	3.902	1.587
	8	10.955	8.069	5.435	5.491	2.628	2.796	1.212
	12	9.121	6.793	4.655	4.729	2.328	2.466	0.944

Notes:
1. Time-to-plant = 24 hr
2. Base cost/sea day = $5000
3. Safety factor = 1.0
4. Port days/cruise = 10
5. Ship speed = 15 or 18 kt

Notes:	1.	Time-to-plant	24 hr
	2.	Base cost/sea day	$5,000
	3.	Safety factor	1.0
	4.	Port days/cruise	10

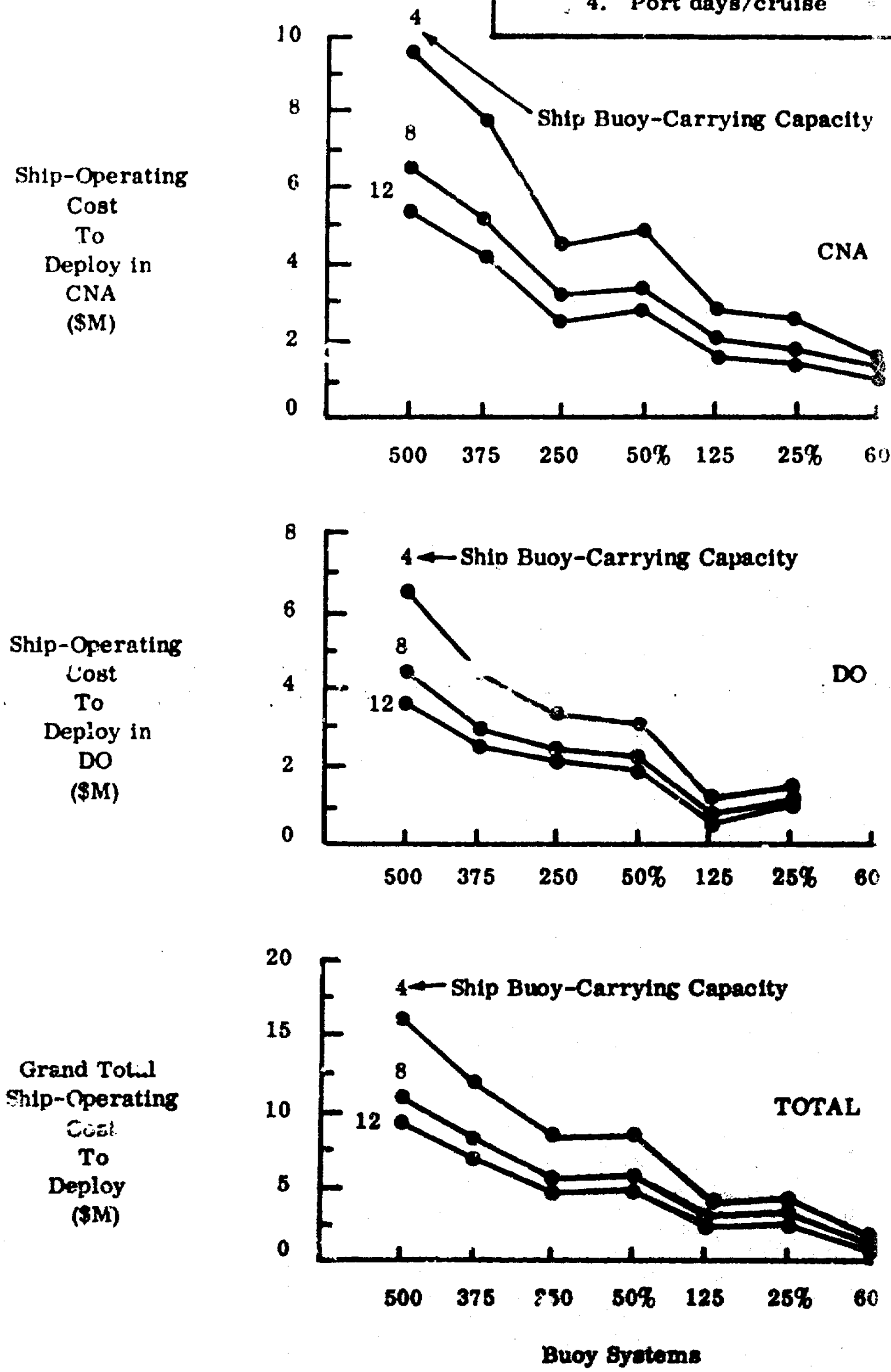


Fig. 5-13. Ship operating cost to deploy buoy systems.

5.5 "Total" Average Ship Operating Cost Per Buoy Planted

The above analyses have not included prorated ship construction costs. In this subsection it will be shown that the inclusion of such prorated costs has little effect on the material presented and conclusions drawn thus far.

Figure 5-14 shows prorated ship construction cost per day based on a 20-year lifetime, for the ship construction costs previously given in Table 3-2. The data for these curves is given in Table 5-4.

Equation 3 shows the expression used to compute "total" average ship operating cost per buoy planted.

$$\text{"Total" Average Ship Operating Cost Per Buoy Planted} = C_{avg} + \frac{S_1}{7300} \times D_1 \qquad \text{(Eq. 3)}$$

Where

S_1 = Total cost of ship construction ($)

D_1 = Average Time per Buoy Planted (days)

Figure 5-15 shows "total" average ship operating cost per buoy planted for 500-buoy baseline system deployments in the East Coast MDZ and the North Atlantic MDZ. These are representative of other results obtained throughout the study and clearly indicate that with minor exceptions, increased ship buoy-carrying capacity at speeds of 15 or 18 kt leads to reduced total average cost per buoy planted.

Because of the consistency of results such as those indicated in Fig. 5-15, prorated ship construction costs have <u>not</u> been used in presenting results and illustrations throughout the remainder of this report, because real costs were considered to be of more interest than prorated (i.e., amortized) costs.

TABLE 5-4
PRORATED SHIP CONSTRUCTION COSTS PER DAY* ($K)

Ship buoy-carrying capacity	Ship speed (kt)							
	9	12	15	18	21	24	27	30
4	1.08	1.08	1.08	1.47	2.01	3.51	4.32	5.34
6	1.47	1.47	1.47	1.47	2.8[illegible]	↓	↓	↓
8	1.59	1.59	1.59	[illegible]	↓	↓	↓	↓
10	2.25	2.25	2.25	2.25	↓	↓	↓	↓
12	2.25	2.25	2.25	2.25	↓	↓	↓	↓

*20-year lifetime (7300 days) assumed.

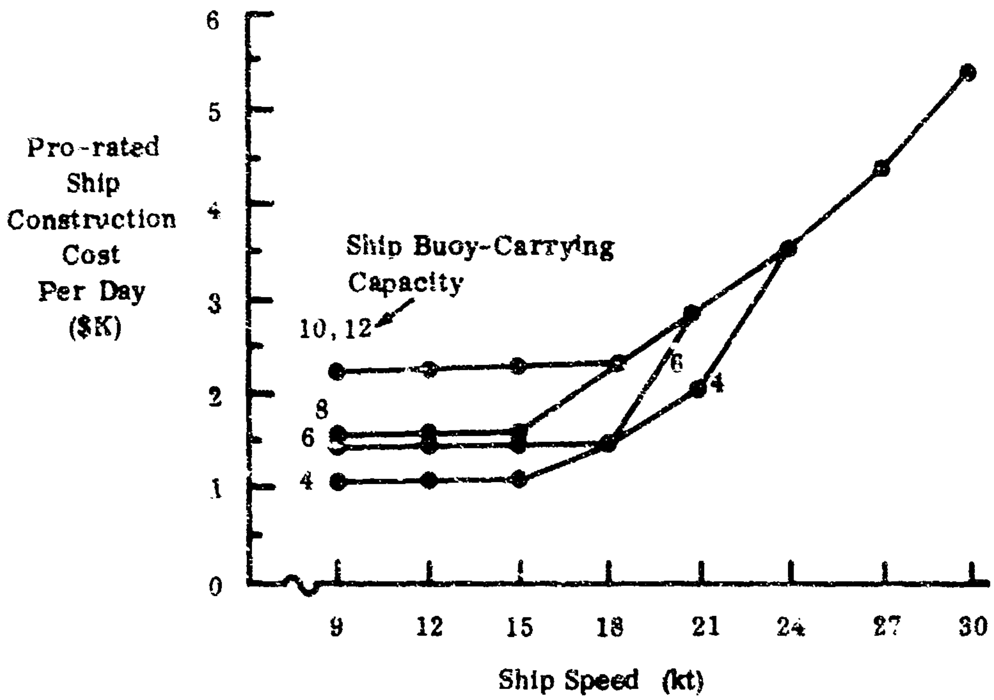


Fig. 5-14. Pro-rated ship construction cost per day (20-yr lifetime).

Notes: 1. Time To-Plant - 24 hr
2. Base Cost/Seaday = $5,000
3. Safety Factor = 1.0
4. Port Days/Cruise = 10

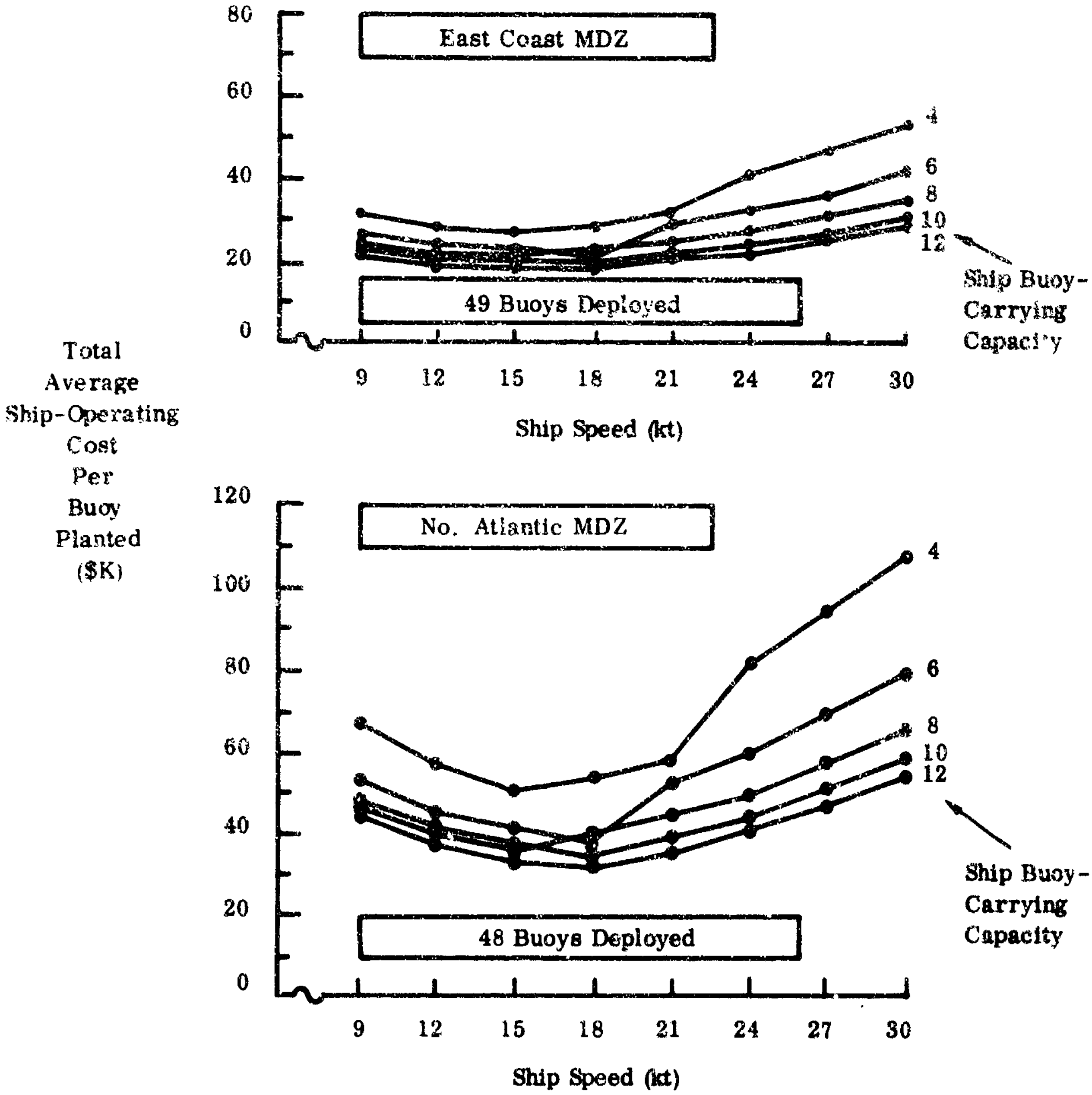


Fig. 5-15. Ship speed and buoy-carrying capacity trade-off.

5.6 Sensitivity of Average Cost Per Buoy Planted to Variations in Cost Factors

5.6.1 Sensitivity to Variations in Base Cost Per Sea-Day

Average ship operating cost per buoy planted depends primarily on base cost per sea-day. The rationale for various choices of base cost per sea-day has been given in Section 3, where it was noted that in essence base cost per sea-day reflects crew cost, which in turn is a function of the level of automation in ship operation and the amount of planned, on-board refurbishment of buoys.

The TRC buoy deployment/maintenance model provides the opportunity to vary base cost per sea-day. Three values were used in this study: $2000, $5000, and $8000 per day. The sensitivity of average cost per buoy planted to variations in base cost per sea-day is shown in Fig. 5-16a. Base cost per sea-day applies to all days at sea and in port*; therefore, average cost per buoy planted varies as a linear function of base cost per sea-day. As the number of sea-days per buoy planted decreases (as is the case in going from the 4-buoy to the 12-buoy ship) sensitivity of average ship operating cost per buoy planted also decreases.

The rate of change of average ship operating cost per buoy-planted is indicative of the sensitivity of this factor to changes in base cost per sea-day. The rate of change (slopes of the curves in Fig. 5-16a) is shown in Fig. 5-16b. This figure indicates that the sensitivity has decreased to the point where a variation of one dollar in base cost per sea-day for the 12-buoy ship has the net effect of creating about a $2.50 change (in the same direction) in average ship operating cost per buoy planted. Of course, curves such as that in Fig. 5-16b delineating cost sensitivity differ from MDZ to MDZ. The nature of this difference is shown in Fig. 5-17, which illustrates the point that the average cost variation in CNA MDZs for the 10 and 12-buoy ships is relatively minor, and tends to average approximately $2.50 change in average cost per buoy planted per dollar change in base cost per sea-day. In the DO MDZs, the factor is approximately $3.50 per dollar change in base cost. Thus, it is apparent that what might appear to be rather small improvements in reducing base cost per sea-day might be increased by a factor of about 3 in the reduction of average cost per buoy planted.

*Cost per port day was specified by the NDBS DPO to be 94% of base cost per sea-day.

Notes: 1. MDZ = Gulf of Mexico
2. Time-to-plant = 24 hr
3. Safety Factor = 1.0
4. Port Days/Cruise = 10
5. Buoys Deployed = 60

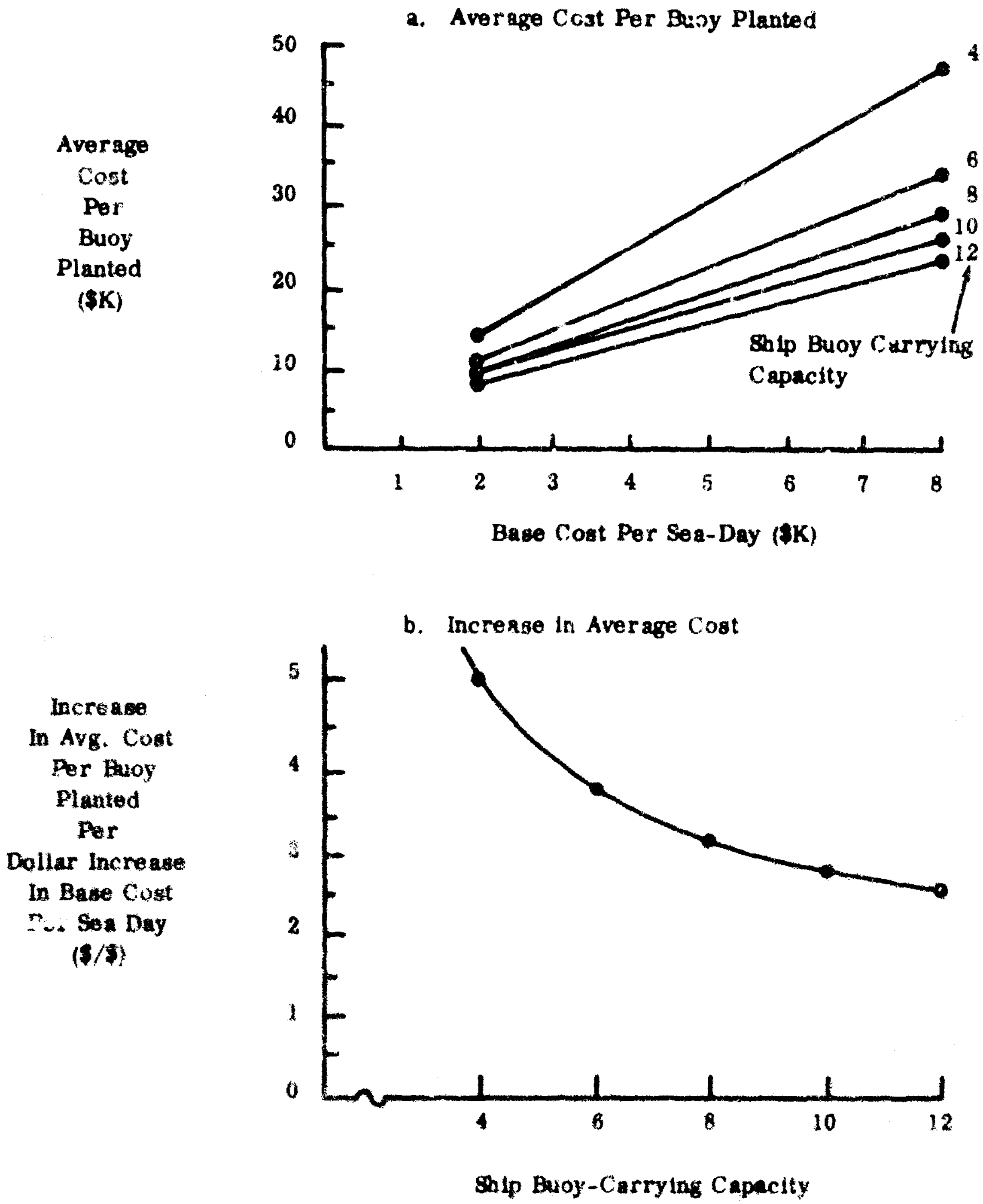


Fig. 5-16. Sensitivity of average cost per buoy planted to variation in base cost per sea day. (Gulf of Mexico MDZ.)

Notes:	1. Time-to-plant = 24 hr
	2. Safety Factor = 1.0
	3. Port Days/Cruise = 10
	4. Data Average Across Ship Speeds of 15, 18 kt
	5. No. Buoys Planted = 500

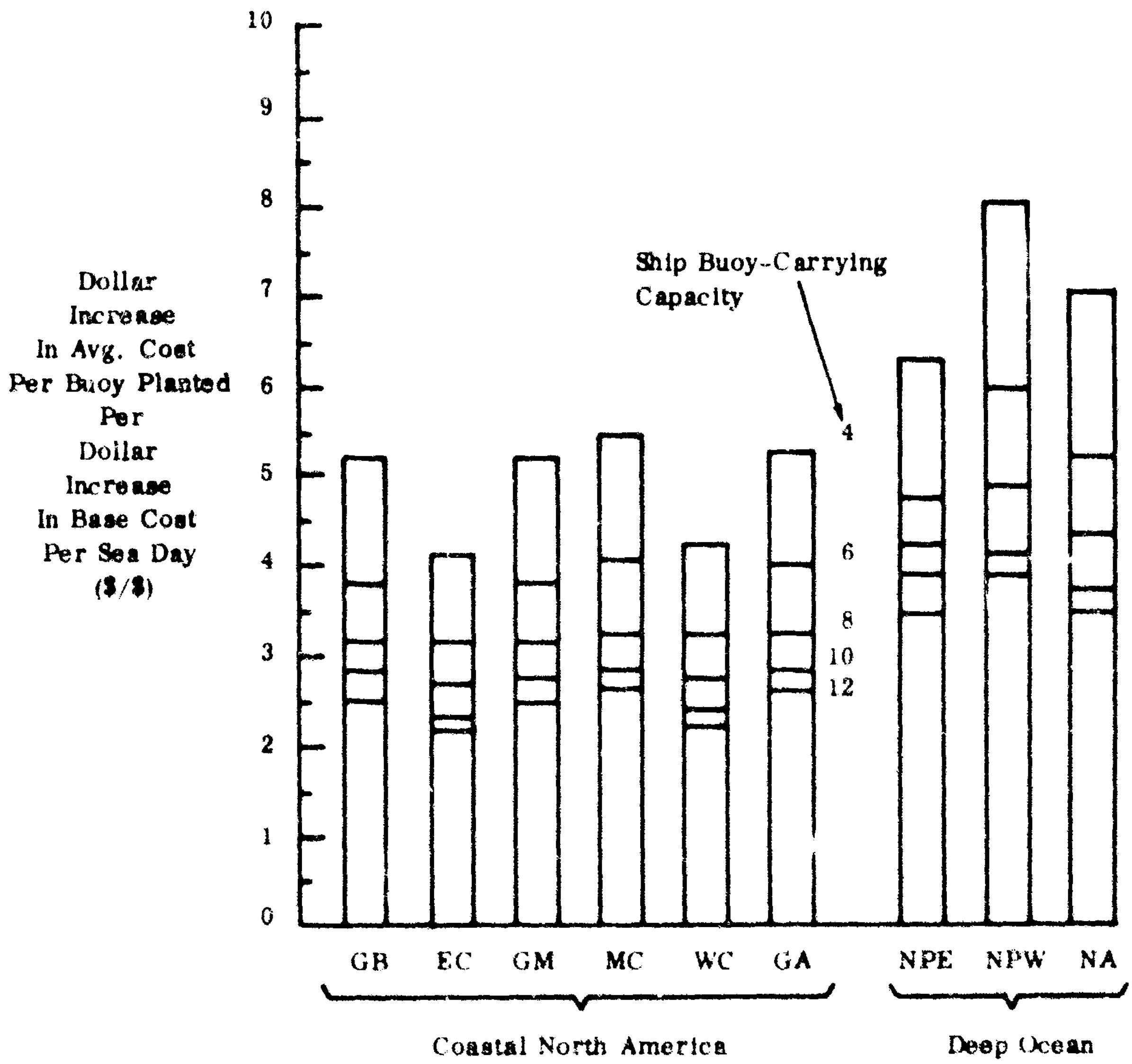


Fig. 5-17. **Sensitivity of average cost per buoy deployed to variation in base cost per sea day.**

5.6.2 Sensitivity to Variations in Time-to-Plant

Throughout this report a time-to-plant each buoy of 24 hours has been used. The buoy deployment/maintenance model has provision for variation in time-to-plant and 12, 24, 30, and 36 hours have been used. The sensitivity of average ship operating cost per buoy planted to variations in time-to-plant each buoy is given in this subsection.

Time spent on station deploying buoys results in ship operating costs comprised of the base cost per sea-day and the ship maintenance cost per day. Ship maintenance cost per day is a function of ship speed and ship buoy-carrying capacity as shown in Fig. 5-1. Once ship speed and ship buoy-carrying capacity have been fixed, the sensitivity of average ship operating cost per buoy planted becomes a linear function of time-to-plant each buoy. For example, for a 4-buoy ship operating at 18 kt and a base cost per sea-day of $5000, the ship maintenance cost per day is $306, resulting in a linear factor of $5,306 per 24 hours time-to-plant relating average ship operating cost per buoy planted to time-to-plant each buoy. (That is, the change in average cost per buoy planted is $221 per hour variation in time-to-plant.) In the case of a 12-buoy, 18 kt ship, the sum of base cost per sea-day and ship maintenance cost per sea-day is $5,600 per day resulting in a sensitivity of average ship operating cost per buoy planted of $233 per hour time-to-plant. These statements are illustrated in Fig. 5-18 which shows sensitivity of average ship operating cost per buoy planted to variation of time-to-plant in the baseline East Coast MDZ and North Atlantic MDZ. The slopes of curves for comparable ship buoy-carrying capacity are the same in all MDZs. For the 500-buoy baseline system a reduction of one hour time-to-plant would result in a net saving of $117,000 over the entire system, given all the conditions noted in Fig. 5-18.

5.7 Buoy System Deployment Time

A factor of considerable interest in NDBS development planning is the total deployment time (in ship-days) required to implant buoys in MDZs or in the CNA or DO region, or for the combination of both CNA and DO regions. These factors are discussed in this subsection.

Notes:
1. Buoy System = 500
2. Base Cost/Sea Day = $5,000
3. Safety Factor = 1.0
4. Port Days/Cruise = 10
5. Ship Speed = 18 kts

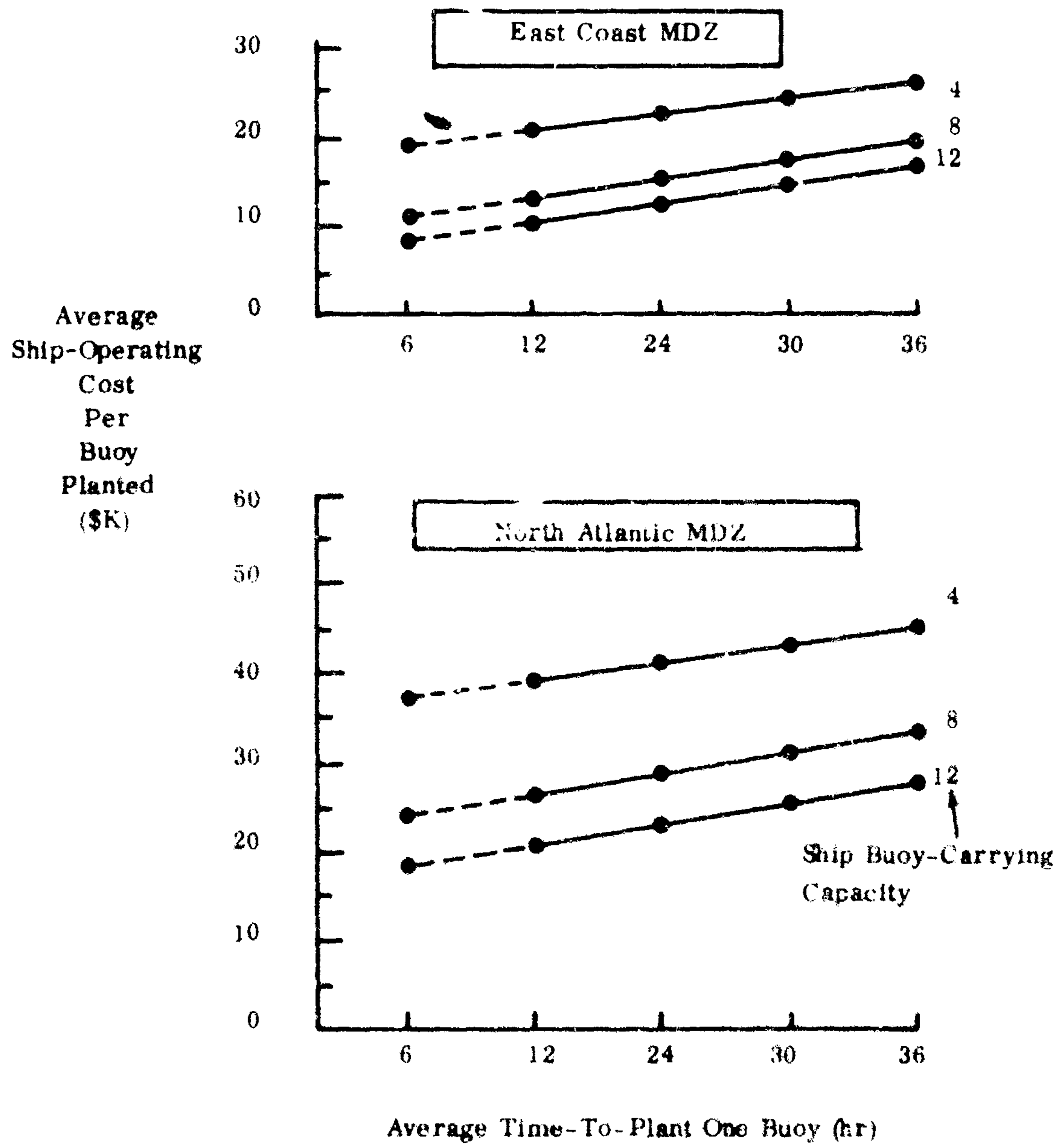


Fig. 5-18. Sensitivity to time-to-plant.

Figure 5-19 shows total minimum deployment ship-days* for each of the nine Modular Deployment Zones for the 500-buoy baseline system. The reduction in deployment ship-days achieved by using ships of high buoy-carrying capacity is made evident by Fig. 5-19. On a normalized basis, minimum average deployment time in ship-days per buoy planted is given in Fig. 5-20a. It is evident that for the 12-buoy ship, minimum average deployment time is approximately 2.25 ship-days per buoy planted in the CNA MDZs and about 3.2 ship-days per buoy planted in the DO MDZs. One day of each of these values is assumed to be spent on-station deploying the buoy. A second day (approximately) is spent in port. Thus, the average time traveling per buoy deployed for the 12-buoy 18 kt ship is about 0.25 days for CNA buoys and 1.4 days for DO buoys.

Using the minimum average deployment time for each MDZ and a ship operating year of 335 days (allows 60 days dry-dock time every two years), it is possible to determine the maximum number of buoys one ship would be capable of deploying in one year. This information is given in Fig. 5-20b. Note for this figure that the 12-buoy, 18 kt ship provides the greatest deployment capability, numbering between approximately 120 and 140 buoys per year (maximum) in the CNA MDZs and about 90 buoys per year in the Deep Ocean MDZs. These figures are, of course, for a safety factor of 1.0. A more conservative planning factor might be about 90 buoys per ship year for CNA MDZs and about 70 buoys per ship year for Deep Ocean MDZs.

As has been noted elsewhere, a potential bound on the number of buoys deployed per cruise (or per ship year) depends in part on the maximum cruise time allowed. Figure 5-21 shows that the maximum cruise time in CNA MDZs is within the 22.5 day desired maximum cruise time (as specified by the NDBS DPO) with the exception of the Gulf of Alaska MDZ where the 12-buoy ship would require a maximum cruise time of about 24 days, under ideal conditions.† In all Deep Ocean MDZs the problem is more

*Total minimum deployment time is the time required to deploy a given number of buoys in a given region, for given ship characteristics and port-days per cruise, without regard to bad weather or other adversities (i.e., safety factor of 1.0). In actual practice, total deployment time might be 10 to 30 per cent greater than the (ideal) total minimum deployment time.

†Actual cruises can be longer than 22.5 days. Applying a safety factor of 4/3 to an actual allowed cruise time of 30 days results in desired cruises of 22.5 days duration, under ideal conditions (safety factor of 1.0).

Notes:	1. No. Buoys Deployed = 500
	2. Time-to-plant = 24 hr
	3. Safety Factor = 1.0
	4. Port Days/Cruise 10
	5. Ship Speed = 18 kt

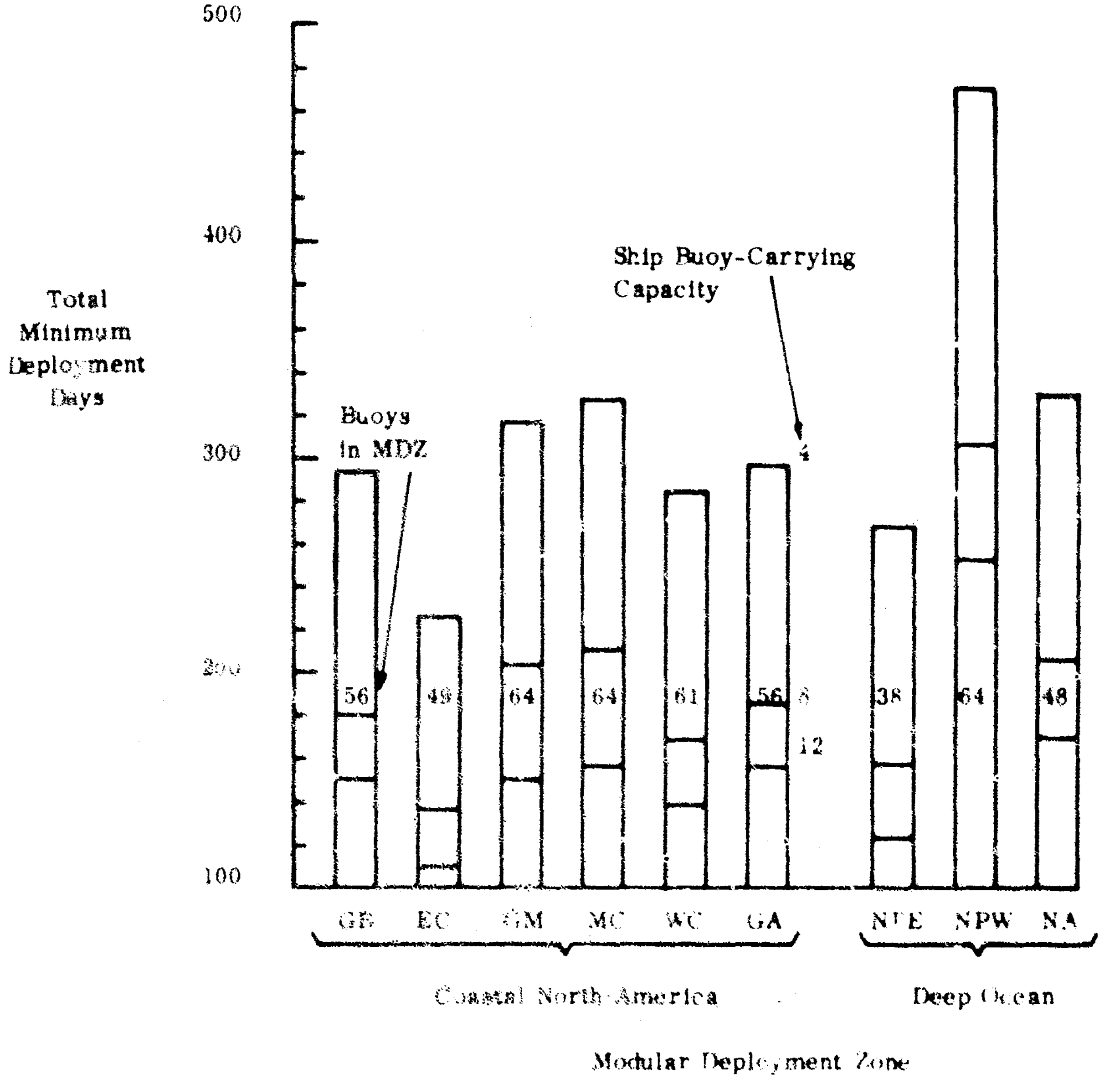


Fig. 5-19. Total minimum deployment days per modular deployment zone

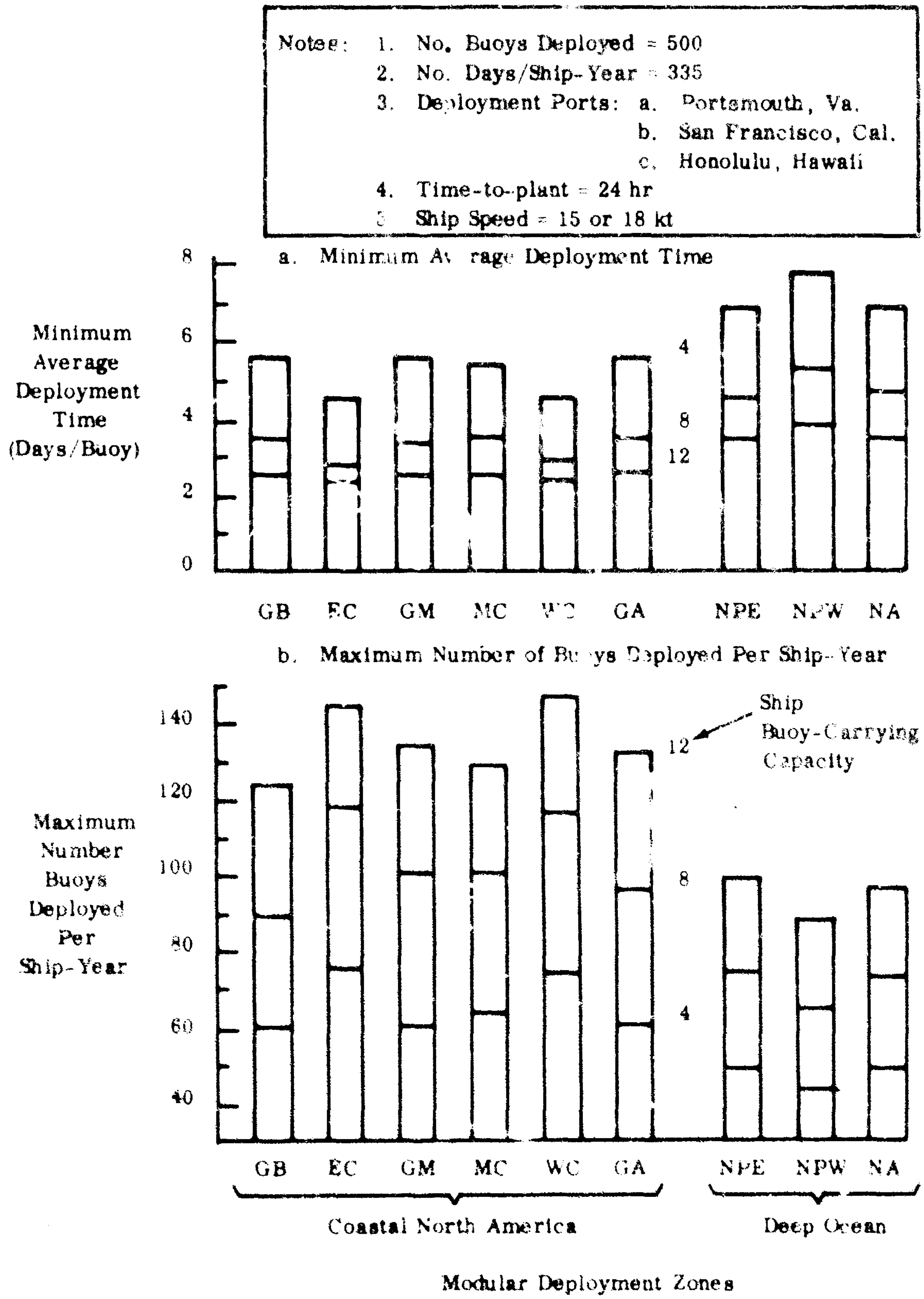


Fig. 5-20. **Maximum number buoys deployed per ship-year and minimum average deployment time.**

Notes:	1.	No. Buoys Deployed	500
	2.	Time-to-plant	24 hr
	3.	Safety Factor	1.0
	4.	Ship Speed	18 kt
	5.	Port Days/Cruise	10

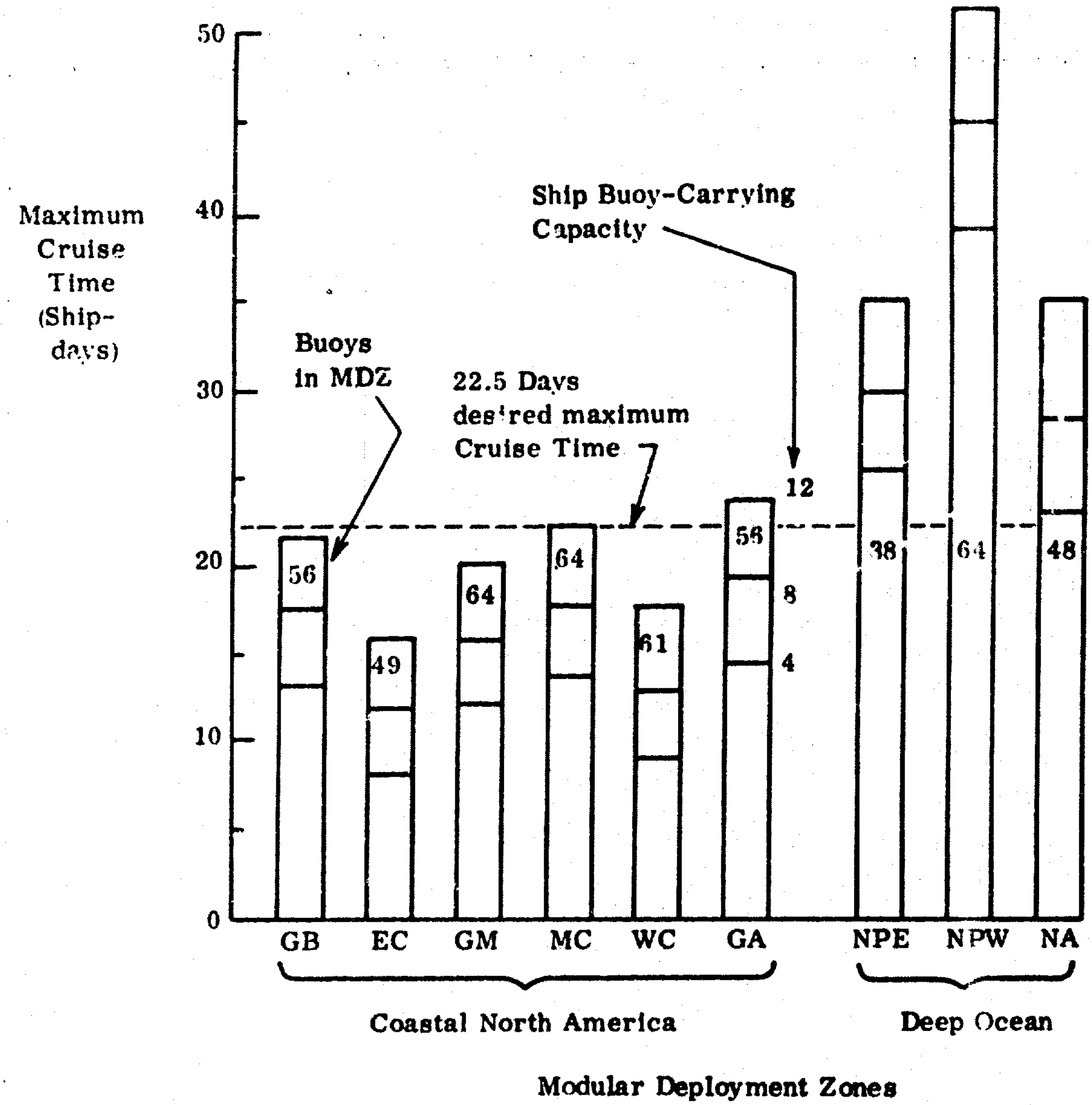


Fig. 5-21. Longest cruise time per modular deployment zone.

crucial. If maximum cruise time for ideal conditions is increased to 30 days, then number of buoys carried by the 18 kt ship on long cruises probably should not exceed eight. Of course, this comment is dependent upon the assumption of 24 hours time-to-plant each buoy and 10 port days per cruise.

Since maximum deployment time in CNA MDZs does not appear to be a problem, concentration of interest is placed on DO MDZs. In particular, Fig. 5-22 shows maximum cruise time for the 18 kt ship carrying 4, 8, and 12 buoys in the North Atlantic MDZ, which is considered to be a typical DO MDZ. Figure 5-22 makes evident the fact that maximum cruise time will be of the order of at least 35 days (minimum) for efforts to implant 24 or more buoys throughout the North Atlantic MDZ. Even when the number of buoys in the North Atlantic MDZ is only 12 and they are confined primarily to the major shipping lane between the U.S. and Europe, minimum cruise time will be of the order of 29 days. (Of course, under such conditions only one cruise would be required by the 12-buoy ship to deploy all 12 North Atlantic MDZ buoys).

It is not the purpose of this report to attempt to establish policy regarding maximum tolerable cruise time. That is a function of the operating agency deploying (and/or maintaining) buoys in a future NDBS. The TRC buoy deployment/maintenance model does, however, provide insight as to the potential capabilities of ship speed and buoy-carrying capacity combinations applied to the anticipated deployment/maintenance tasks of the future NDBS. In this context, then, it is evident that cruises of long duration will likely be encountered in deploying and/or maintaining data buoys in DO MDZs, or it will require many cruises involving small numbers of buoys each cruise.

As a final point to be made in this section, Fig. 5-23 shows total minimum deployment time required to deploy all CNA buoys, all DO buoys and combinations of all DO and CNA buoys for all seven buoy systems. The figure indicates that approximately 1400 ship-days would be required (as a minimum) to deploy the 500-buoy baseline system, while 1045 ship-days (minimum) would be required to deploy the 375-buoy system. Other times are commensurate with the number of buoys deployed. All these data are presented in Table 5-5, which shows not only total minimum deployment time by buoy systems, but also minimum average deployment time per buoy and the maximum number of buoys deployed per ship-year for each of the seven buoy systems. The last column of Table 5-5 shows the minimum number of ships required to deploy each

Notes:				
	1.	Time-to-plant	=	24 hr
	2.	Base cost/sea day	=	$5,000
	3.	Safety factor	=	1.0
	4.	Port days/cruise	=	10
	5.	Ship Speed	=	18 kts

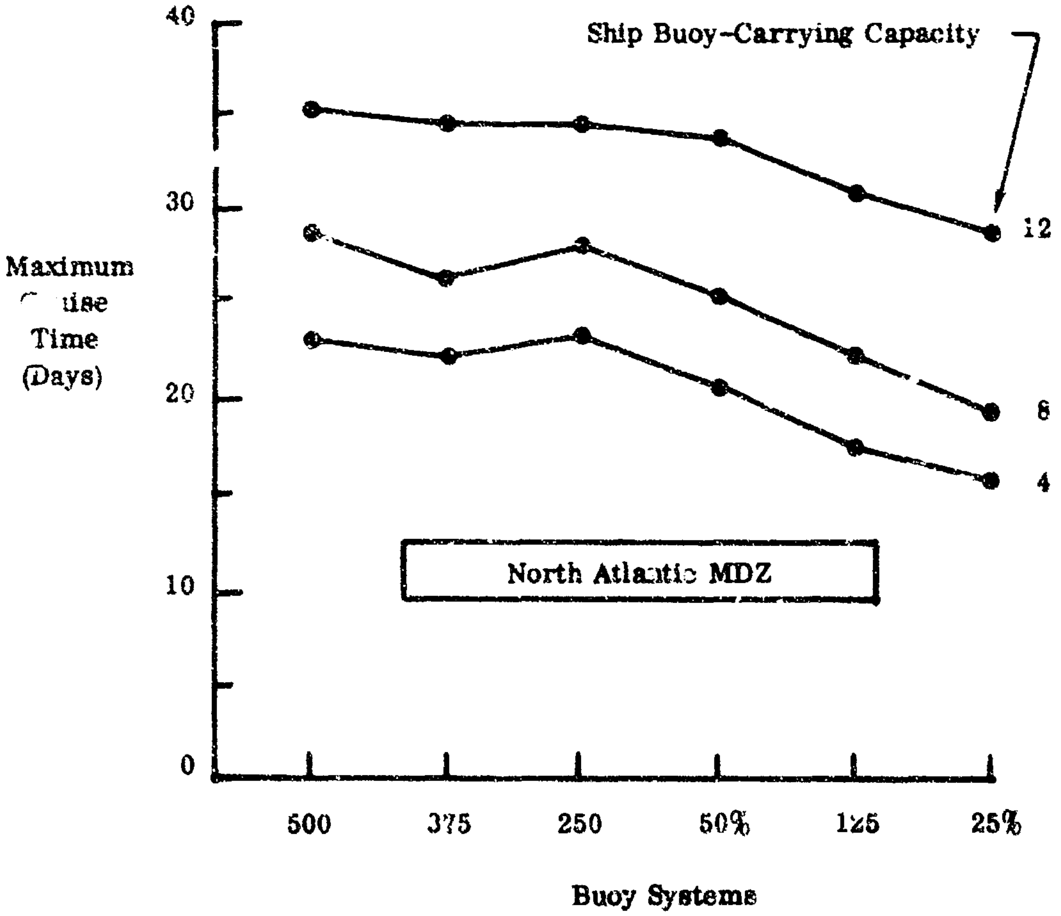


Fig. 5-22. Maximum cruise time for all buoy systems.

Notes:				
	1.	Time-to-plant	=	24 hr
	2.	Base cost/sea day	=	$5,000
	3.	Safety Factor	=	1.0
	4.	Port days/cruise	=	10
	5.	Ship Speed	=	18 kts

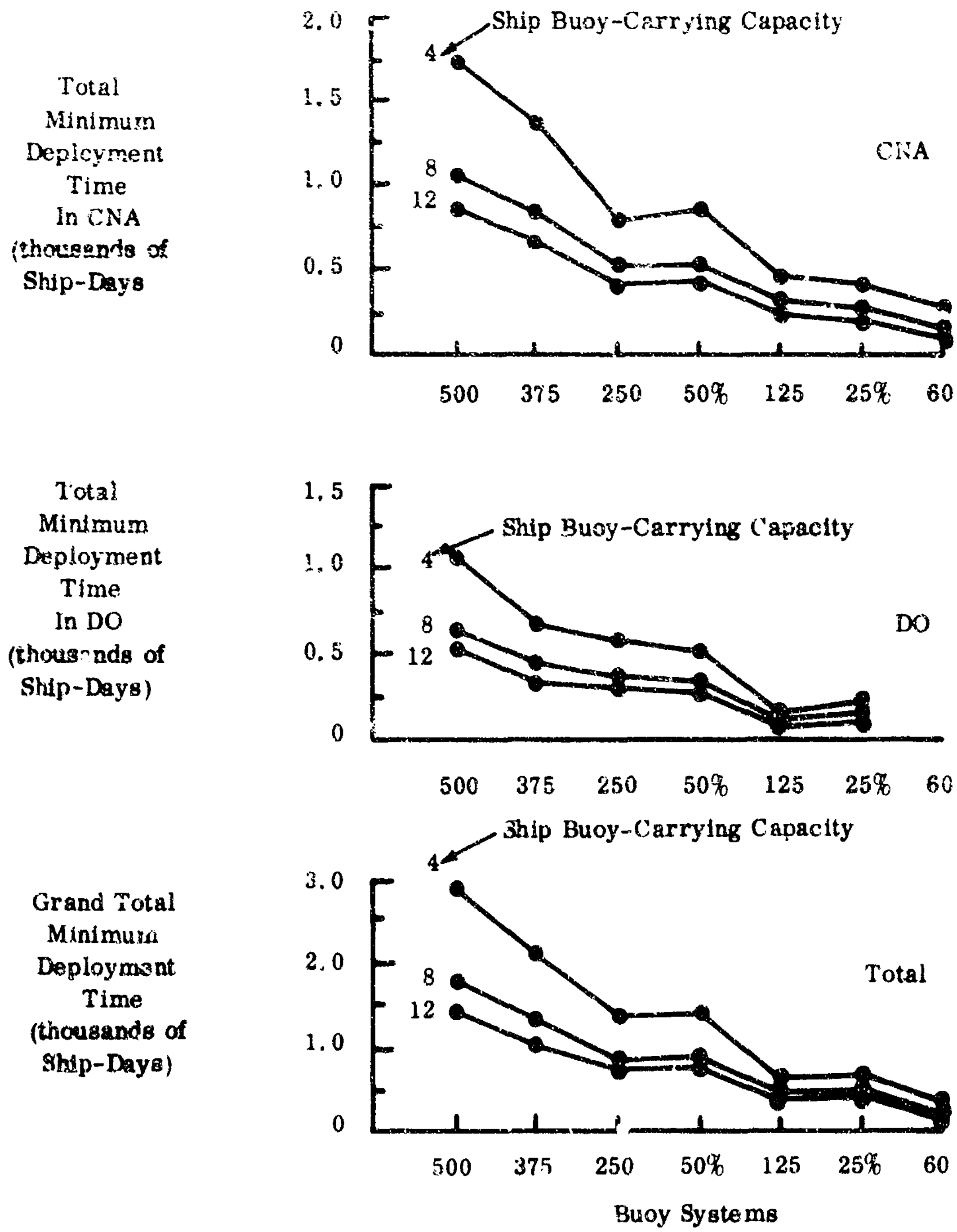


Fig. 5-23. Total minimum deployment time for all systems.

of the seven buoy systems in one year. It must be held in mind that all these figures are for a safety factor of 1.0, 24 hours time-to-plant, and 10 port days per cruise. Variation in any of these influential factors will change the data presented in Table 5-5.

5.8 Buoy Hardware Cost

Buoy hardware costs for all seven buoy systems are presented in this subsection, primarily as an illustration of the capabilities of the TRC buoy deployment/maintenance computer simulation and cost model. The cost figures used here are based on conservatively high cost estimates provided by the USCG NDBS DPO and are not intended for financial planning purposes of long-range significance.

5.8.1 Depth of Mooring

Total buoy cost is determined in part by the cost of the mooring line, which for a buoy with a one-point mooring at a scope of 1.0 is equivalent to the depth of water in which the buoy is moored.* Average mooring depth by MDZ for the 500-buoy baseline system is shown in Fig. 5-24a. In the Gulf of Mexico and Grand Banks MDZs, average mooring depth is between 5200 and 6000 feet. In the other four CNA MDZs, average mooring depth is between 9400 and 11,600 ft. Average mooring depth in the three DO MDZs varies from 11,300 to 13,200 ft.

One of the output features of the TRC buoy deployment/maintenance simulation and cost model is the total length of mooring required for all buoys deployed in a given computer run. (A computer run was made for all buoys in each MDZ. See Appendix A for an example.) Figure 5-24b shows total length of mooring required in each of the nine MDZs. The sum of mooring cable required for all MDZs is 4,982,000 ft. At a cost of $1.75 per ft (dacron cable with central conductors), the investment in mooring cable for the 500-buoy system would be $8,730,000.

The average mooring depth per buoy, considering all buoys in each of the seven systems, is shown in Fig. 5-25; it is seen to be of the order of 10,000 ft. Based on this average mooring depth per buoy, it is clear that the total length of mooring

---

*It is recognized that a taut-line moor usually involves a scope of less than 1.0, due to the elasticity of the mooring line. This fact has not been considered here because of the desire to maintain a one-to-one equivalence between ocean depth and total length of mooring line required. Appropriate conversion factors can be easily applied for scopes other than 1.0. Mooring scope is an input to the buoy deployment/maintenance model and any non-negative value of scope is acceptable.

Notes: 1. No. Buoys Deployed = 500
2. Mooring Grand Total = 4,9[illegible]2,000 ft

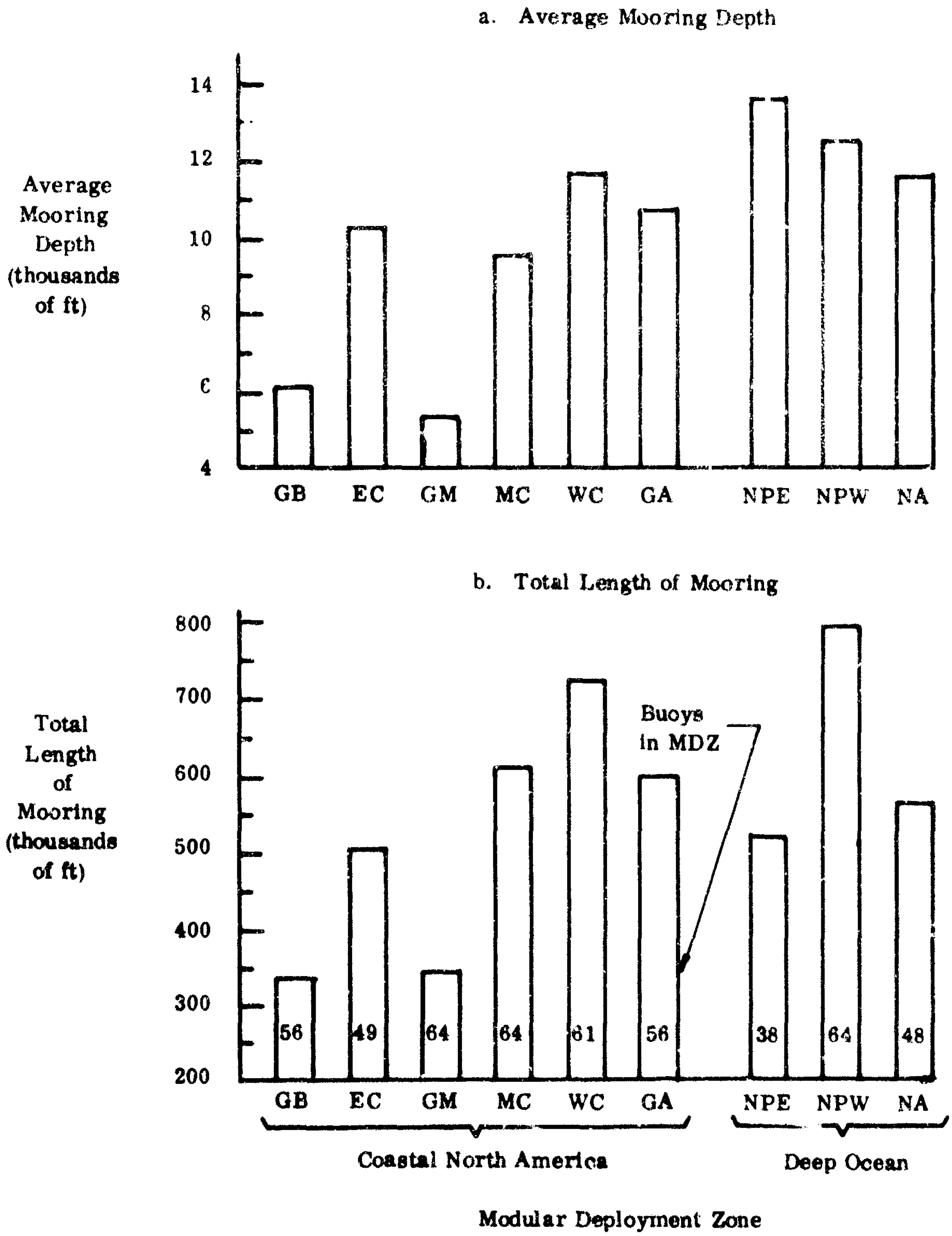


Fig. 5-24. Average mooring depth and total length of mooring.

Notes: 1. Time-to-Plant = 24 hr
2. Base Cost/Sea Day = $5,000
3. Safety Factor = 1.0
4. Port Days/Cruise = 10

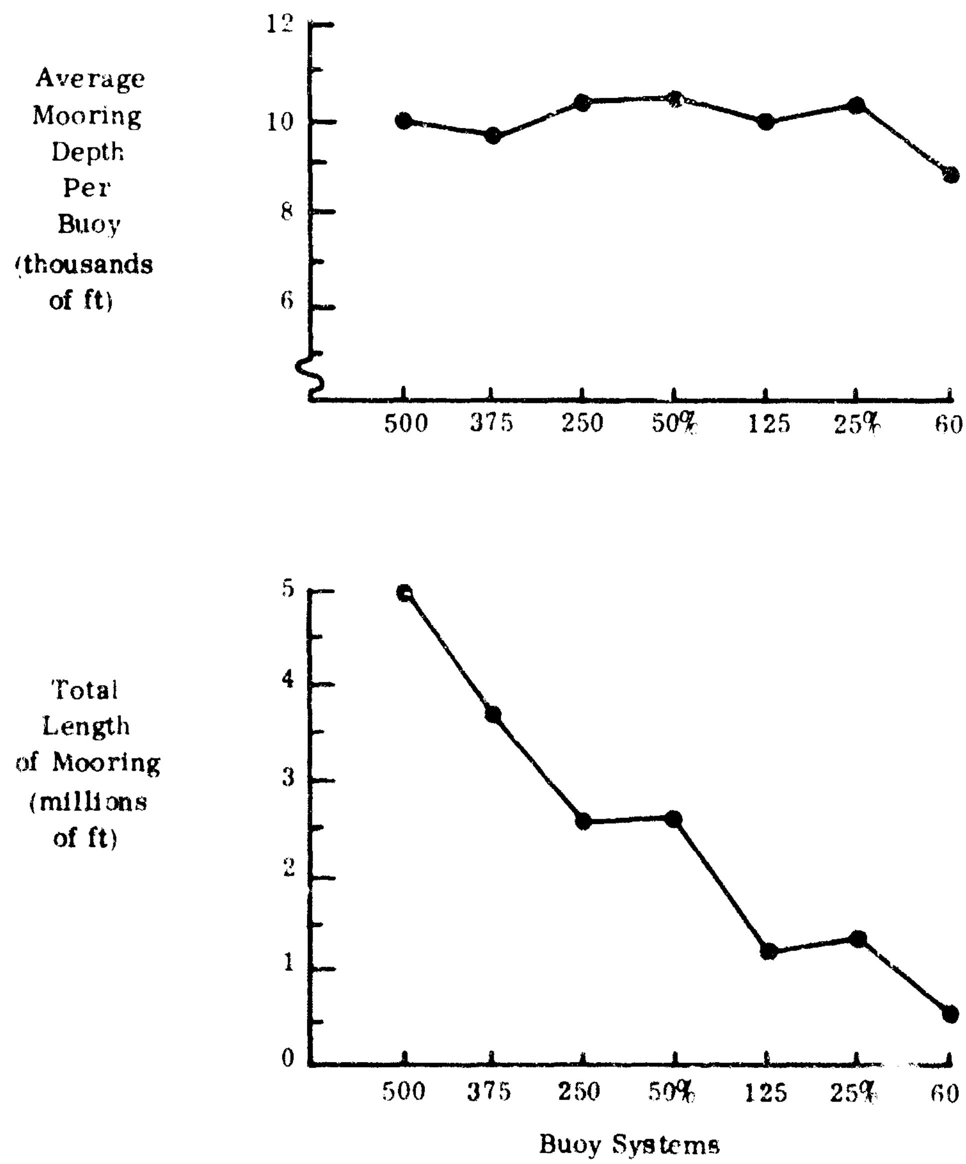


Fig. 5-25. Length of mooring for seven data buoy systems.

TABLE 5-5
BUOY SYSTEM DEPLOYMENT CHARACTERISTICS

Buoy system	Minimum time to deploy (ship days)	Average time to deploy per buoy (days)	Max. No. of buoys planted per ship-year	Min. No. of ships to deploy system in 1 year
500 (baseline)	1400	2.8	120	4.16
375	1045	2.8	120	3.13
250	716	2.88	116.6	2.14
50%	720	2.88	116.0	2.15
125	363	2.9	115.5	1.08
25%	374	2.98	112.2	1.11
60	150	3.5	96	0.623

required for each of the seven data buoy systems is essentially a linear function of the number of buoys in the system. This feature is also illustrated in Fig. 5-25.

5.8.2 Mooring-mounted Oceanographic Sensor Packages

Based on the assumption that 20 IAPSO levels (see Table 5-6) would be instrumented from the surface through 5000 meters depth, the average number of oceanographic sensor packages per buoy can be determined.* This information is another output feature of the TRC buoy deployment/maintenance model. Figure 5-26a presents the average number of oceanographic sensor packages per buoy in the nine MDZs for the 500-buoy system. Table 5-6 lists the IAPSO levels and their equivalent depths. Figure 5-26b shows the total number of oceanographic sensor packages deployed in each MDZ for the 500-buoy system. It has been arbitrarily chosen to deploy a sensor package near the bottom of the mooring cable, if the distance between the bottom and the first IAPSO level above is 0.7 or more of the IAPSO depth increment. In no case

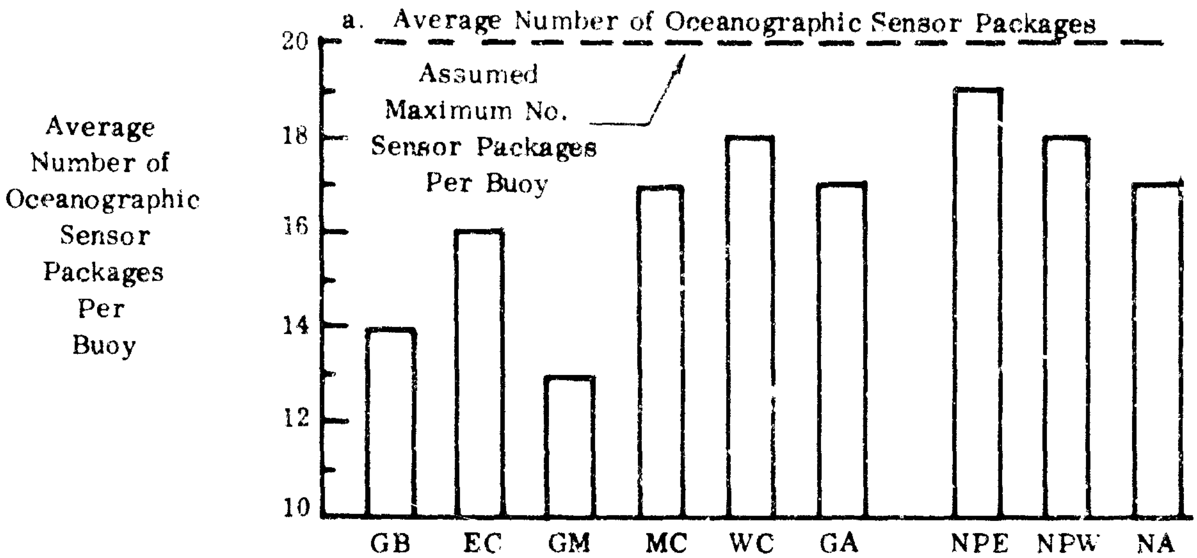
* The selection of the actual number and location of mooring-mounted oceanographic sensor packages has yet to be determined. In fact, it is not clear at this time that discretely instrumented points are necessarily the most reliable and cost effective method of ocean data collection. Other forms of sub-surface data collection may be worth developing.

TABLE 5-6
INTERNATIONAL ASSOCIATION OF PHYSICAL AND
SCIENTIFIC OCEANOGRAPHERS STANDARD OCEAN DEPTHS

Number	Depth	
	(Meters)	(Feet)
1	0	0
2	10	32.82
3	20	65.64
4	30	98.46
5	50	164.1
6	75	246
7	100	328.2
8	150	493
9	200	656.4
10	300	984.6
11	400	1,312
12	500	1,641
13	600	1,970
14	800	2,624
15	1,000	3,282
16	1,200	3,940*
17	1,500	4,930
18	2,000	6,564
19	2,500	8,210*
20	3,000	9,846
21	4,000	13,120
22	5,000	16,410

*These levels have been omitted in this study.

Notes: 1. No. Buoys Deployed = 500
2. Sensor Package Grand Total = 8,38



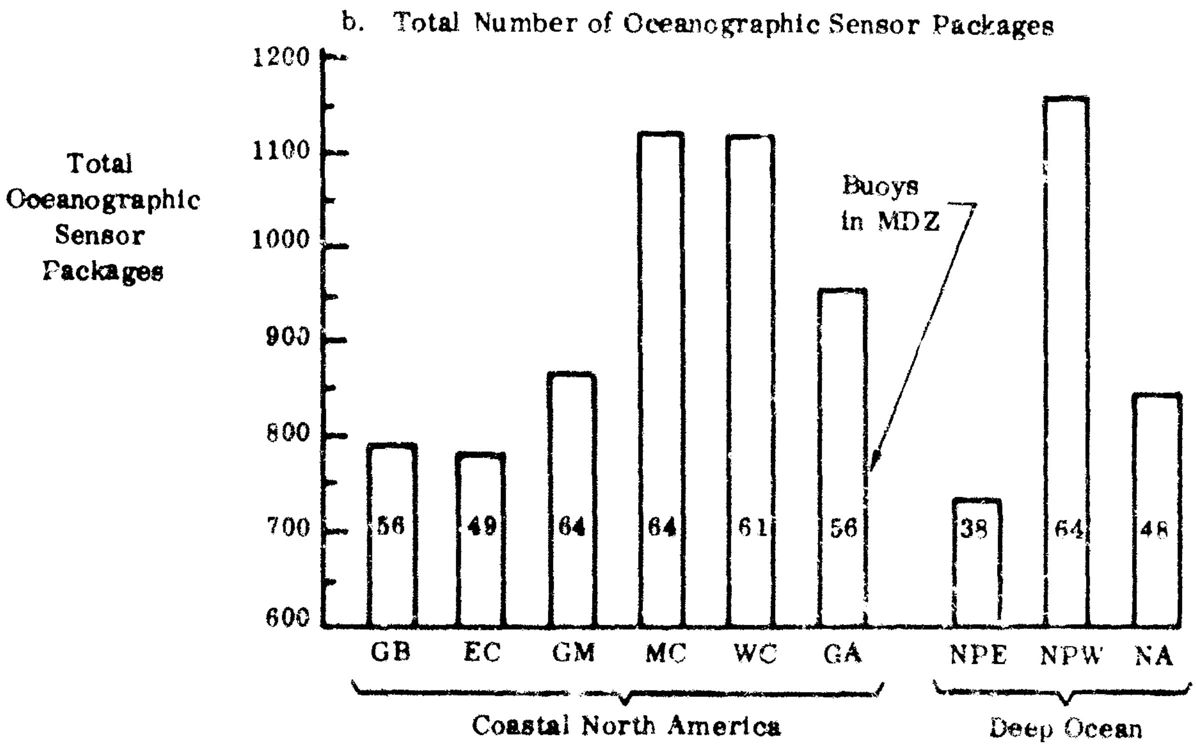


Fig. 5-26. Oceanographic sensor packages.

have more than 20 instrument packages been deployed with one buoy. Figure 5-26 indicates that the total number of sensor packages required for the 500-buoy system is 8,386. At a cost of $7000 each, this represents an investment of $58,702,000.

Figure 5-27 shows the average number of oceanographic sensor packages per buoy required in each of the seven buoy systems. With the exception of the 60-buoy system, the required average number of oceanographic sensor packages per buoy lies between 16 and 17. Figure 5-27 also indicates the total number of sensor packages required by each of the seven data buoy systems. Since the average number of oceanographic sensor packages per buoy is essentially constant at about 16.5 sensor packages per buoy, it is apparent that the total number of oceanographic sensor packages is linearly dependent on the number of buoys in the system, when considering both CNA and DO deployments of more than 100 data buoys.

Based on the buoy component data given in Table 3-4, buoy hardware costs have been computed for all buoys, all MDZs, and each of the seven buoy systems, primarily to provide some insight into the usefulness of the model, once cost figures become firm. Figure 5-28 gives buoy hardware costs in each of the nine MDZs for the 500-buoy system. Baseline system buoy hardware costs per MDZ range from approximately $12 million to $19 million. Total buoy hardware cost for all 500 buoys is $146.4 million. Average buoy hardware costs per Modular Deployment Zone are shown in Fig. 5-29. MDZs having large continental shelf regions are evident (Grand Banks and Gulf of Mexico). The average buoy hardware cost for all buoys in the baseline system is approximately $292,000.

Average buoy hardware cost for all buoys in each of the seven data buoy systems is shown in Fig. 5-30. It is essentially constant at a value of approximately $292,000, regardless of number of buoys in the system. Thus, total hardware cost is a linear function of the number of buoys in the system; this is also shown in Fig. 5-30.

Notes:	1.	Time-to-Plant	= 24 hr
	2.	Base Cost/Sea Day	= $5,000
	3.	Safety Factor	= 1.0
	4.	Port Days/Cruise	= 10

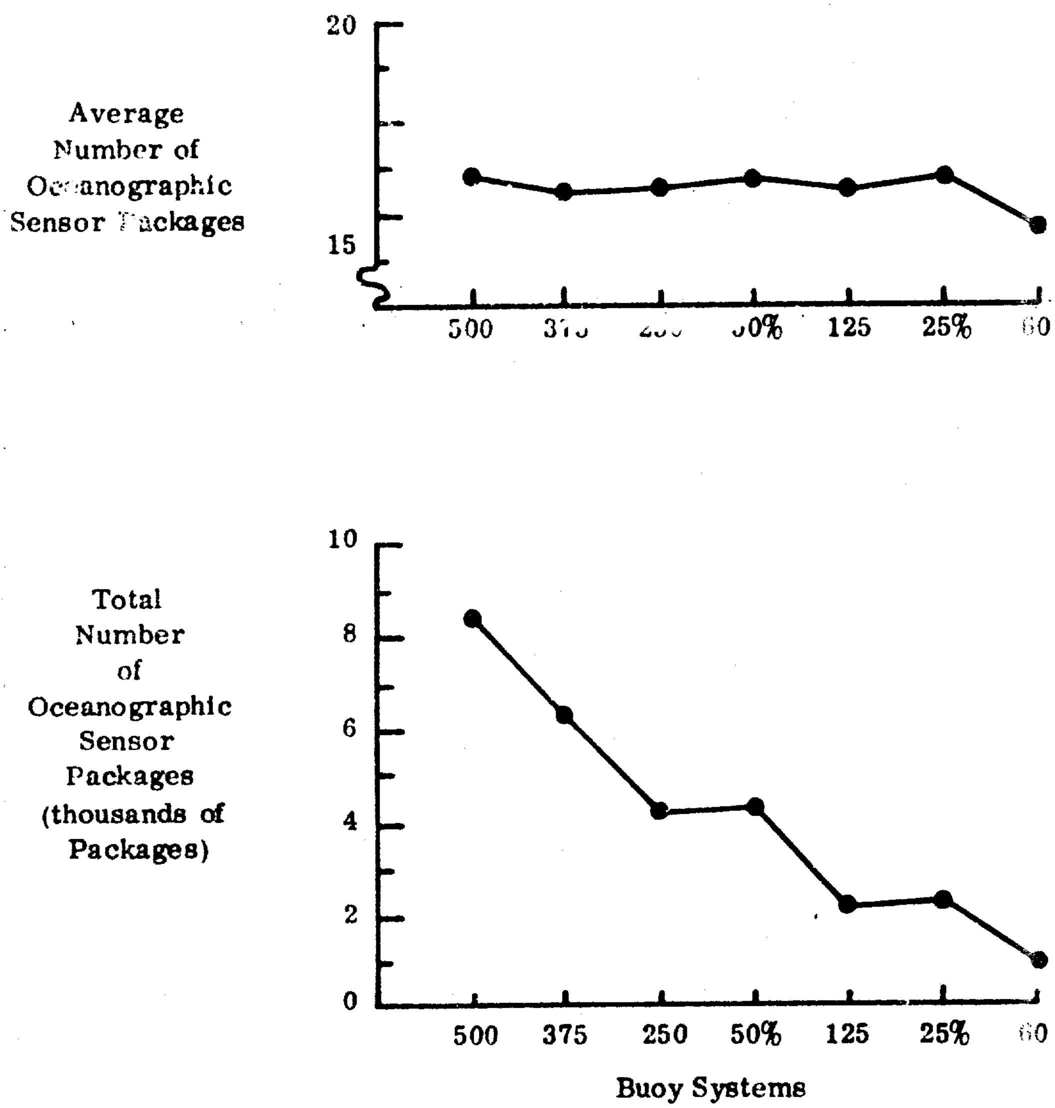


Fig. 5-27. Oceanographic sensor packages for seven data buoy systems.

Notes: 1. No. Buoys Deployed = 500
2. Data for 8 Buoy per Ship Capacity
3. Total Hardware Cost = $146.4 M

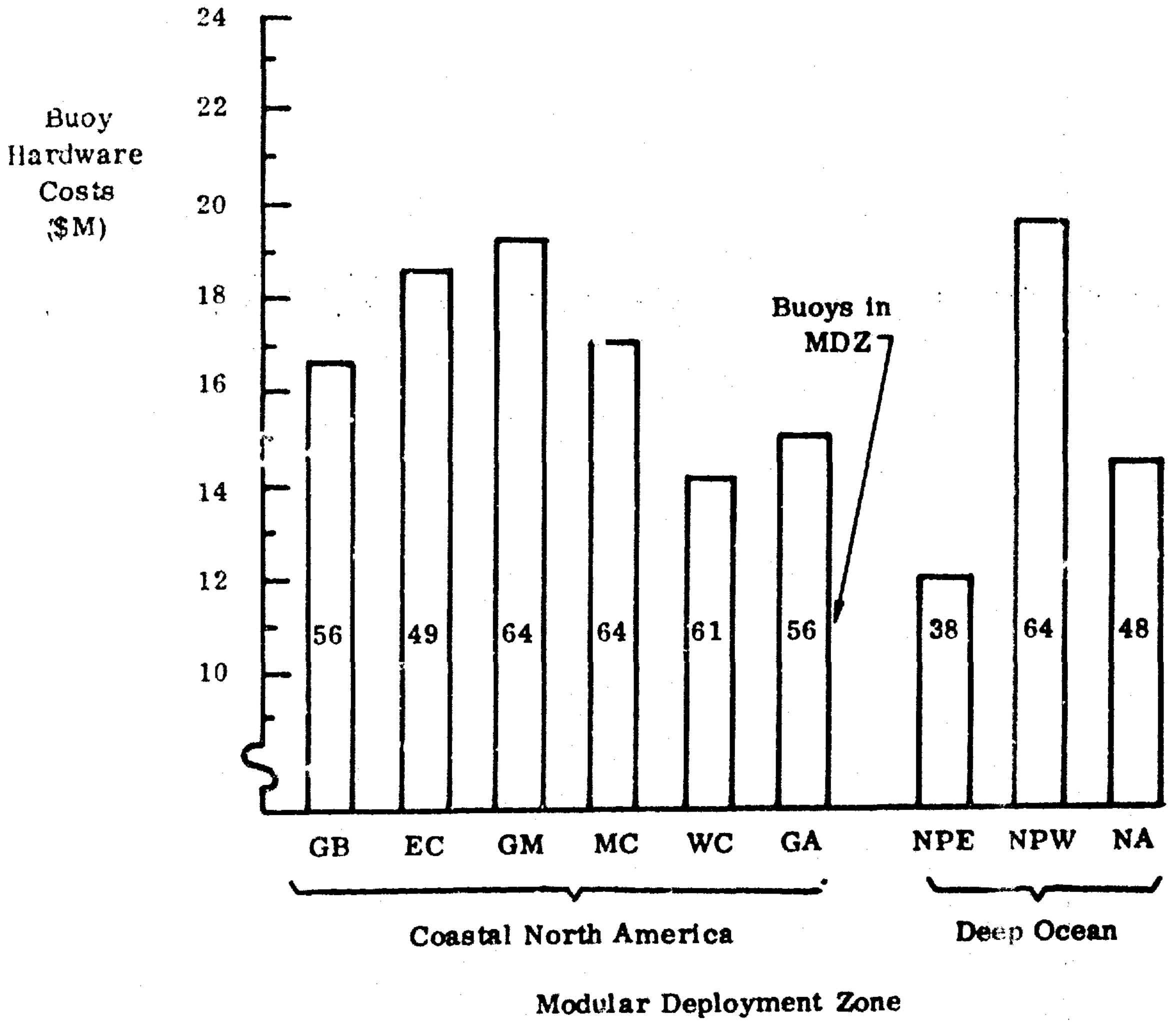


Fig. 5-28. Buoy hardware cost per modular deployment zone ~ baseline system.

Notes: 1. No. Buoys Deployed = 500
2. Data for 8 Buoy per Ship Capacity
3. Total Hardware Cost = $146.4 M

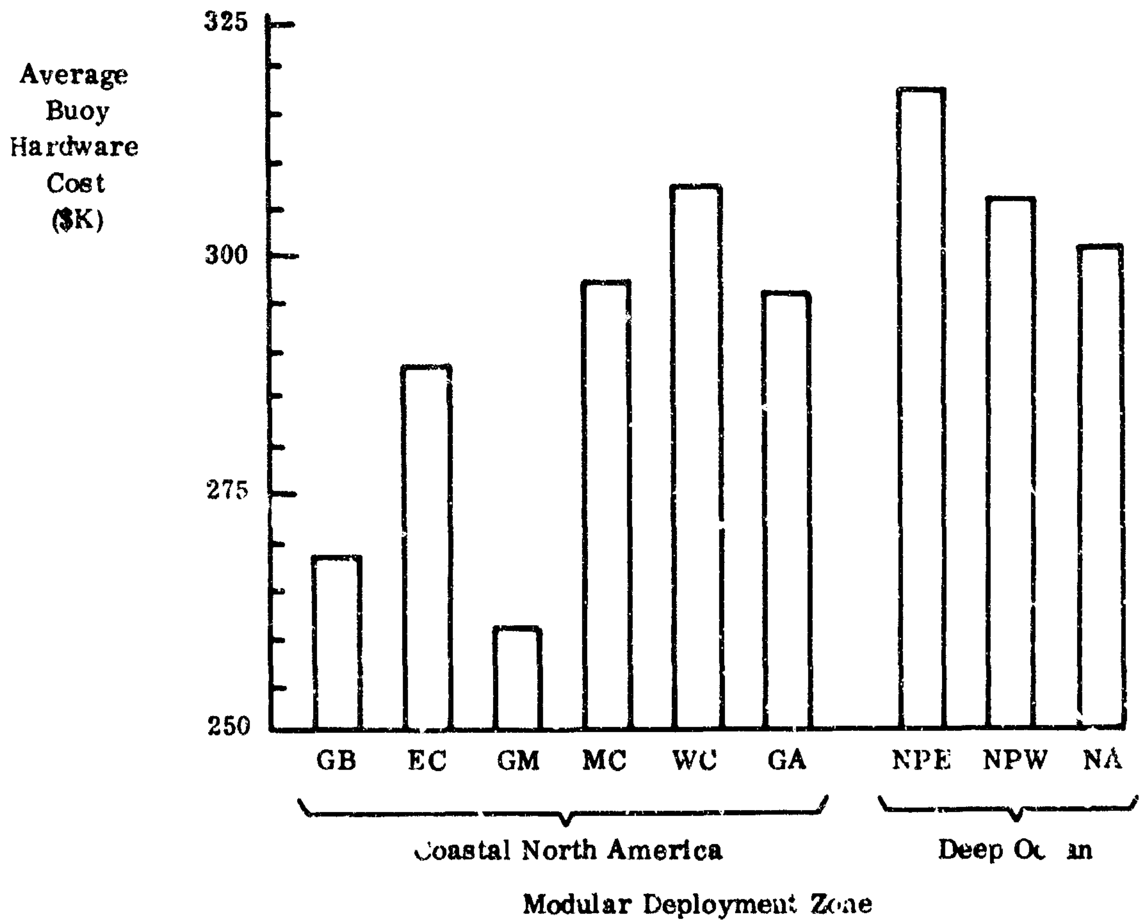


Fig. 5-29. Average buoy hardware cost per modular deployment zone.

Notes:
1. Time-to-plant = 24 hr
2. Base Cost/sea day = $5,000
3. Safety factor = 1.0
4. Port days/cruise = 10

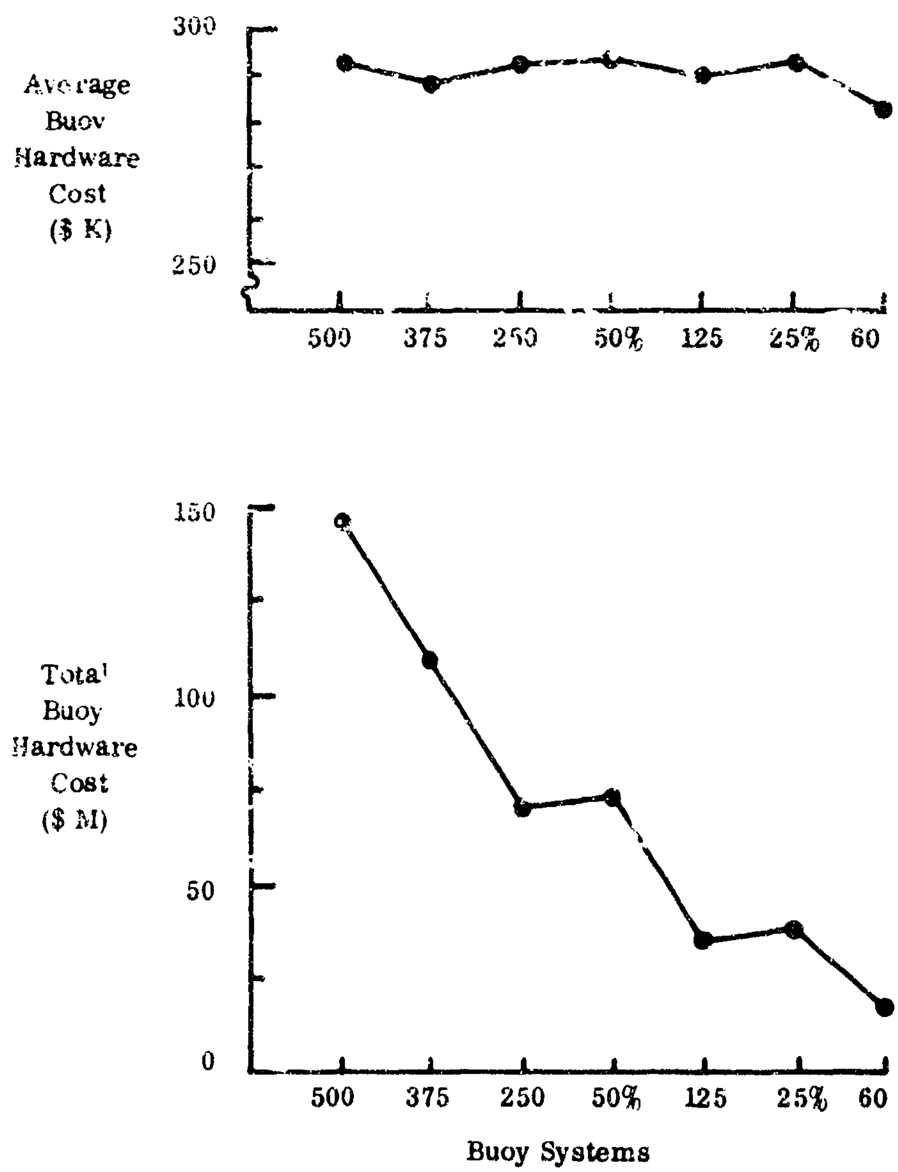


Fig. 5-30. Buoy hardware cost for seven data buoy systems.

6.0 ANALYSIS OF PORT LOCATION ALTERNATIVES

6.1 Introduction

Costs of buoy deployments, time to deploy buoys, and cruise distances presented in the previous section are all dependent in part on the location of the port from which buoys are deployed. All results in Section 5 are based on deployments from three ports: Portsmouth, Virginia; San Francisco, California; and Honolulu, Hawaii. An obvious question immediately arises "How much could be saved in deployment cost, what reduction could be achieved in cruise distance, and how much time could be saved per cruise if deployment in all Modular Deployment Zones took place from a port contiguous to the Modular Deployment Zone?" To a limited degree, a partial answer to this question has been indicated by Fig. 5-9, which shows lower average ship operating costs per buoy planted for East Coast and West Coast MDZs, in comparison to the other 4 CNA MDZs. Also, it was made abundantly clear in Section 5 that deployment of buoys in the North Pacific West MDZ from the port of Honolulu represented highest average costs, greatest cruise distances, and longest cruise time at sea of any of the MDZ deployments considered.

To develop more explicit answers to the question above, an analysis has been undertaken comparing the results of deployments from the above three ports with a group of eight ports. The ports and the MDZs they serve are shown in Table 6-1. The relative location of these ports is shown on global maps in Fig. 6-1.

TABLE 6-1
COMPARISON OF DEPLOYMENT PORT CONFIGURATIONS

Region	Modular deployment zone	Deployment port	
		8-Port config.	3-Port config.
Coastal North America	Grand Banks (GB)	Boston, Mass.	Portsmouth, Va.
	East Coast (EC)	Portsmouth, Va.	Portsmouth, Va.
	Gulf of Mexico (GM)	Galveston, Texas	Portsmouth, Va.
	Mexican Coast (MC)	San Diego, Cal.	San Francisco, Cal.
	West Coast (WC)	San Francisco, Cal.	San Francisco, Cal.
	Gulf of Alaska (GA)	Ketchikan, Alaska	San Francisco, Cal.
Northern Hemisphere Deep Oceans	North Pacific East (NPE)	Honolulu, Hawaii	Honolulu, Hawaii
	North Pacific West (NPW)	Guam	Honolulu, Hawaii
	North Atlantic (NA)	Portsmouth, Va.	Portsmouth, Va.

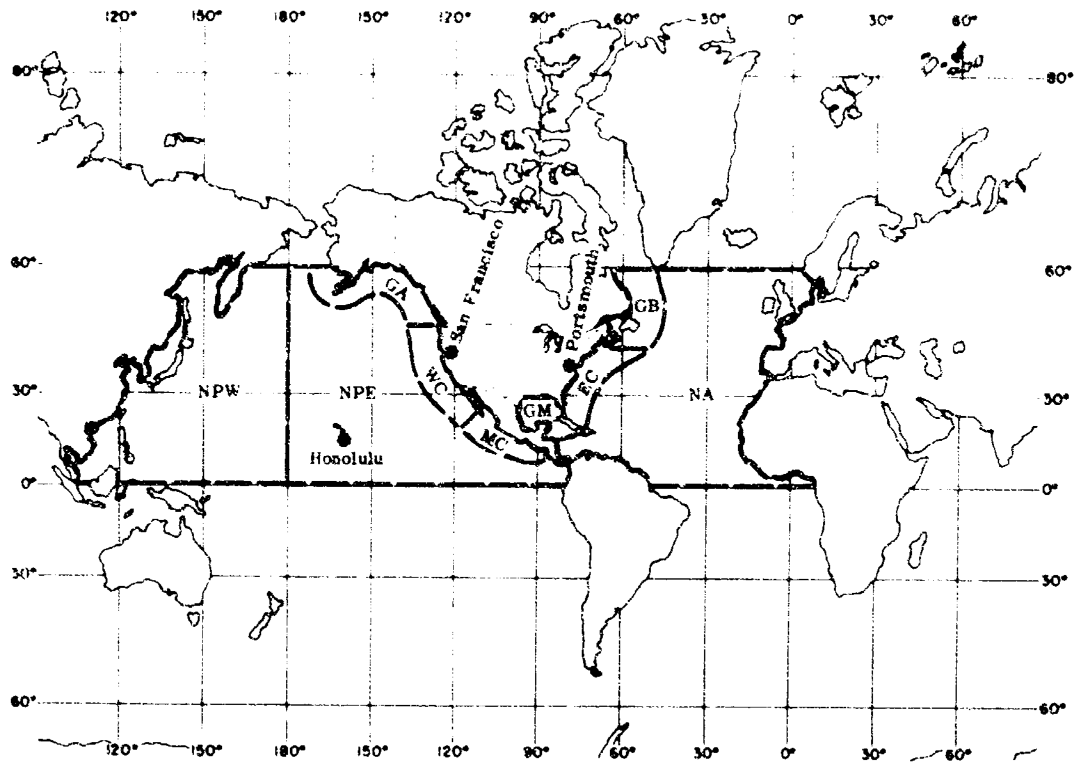


Fig. 6-1a. 3-Port Configuration

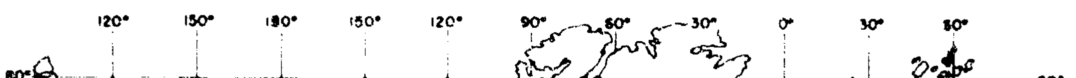


Fig. 6-1b. 8-Port Configuration

6.2 Graphical Comparison of Alternative Port Location Results

To develop a comparison of potential savings in distance and time, the 375-buoy system (75% baseline) has been used. As demonstrated in Section 5, average values are essentially independent of system size for the buoy deployment configurations considered in this study. The 375-buoy system was chosen for this study because of its close similarity to the buoy-spacing requirements TRC obtained from U.S. Government agencies during 1968 [3]. Figure 6-2 shows total distance traveled to deploy the 375-buoy system. The graphical presentation is in three parts, delineating CNA deployment, Deep Ocean deployment, and total deployment. The figure makes evident that the use of eight ports provides a reduction in total distance traveled to deploy all 375 buoys ranging from 83,000 n mi for a 4-buoy ship to about 27,000 n mi for a 12-buoy ship. Figure 6-3 shows average distances traveled per buoy deployed in the CNA, DO, and combined regions. The figure indicates for the 12-buoy ship an average reduction of 63 n mi per buoy for all CNA MDZs and an average reduction of 95 n mi per buoy for the three DO MDZs, when the number of deployment ports is raised from three to eight. Greater reductions of average distance traveled are achieved for the 8-buoy and 4-buoy ships, but the average distances themselves are greater than for the 12-buoy ship. For deployment of all 375 buoys, the average reduction in distance traveled per buoy planted ranges from 220 n mi per buoy for the 4-buoy ship to 72 n mi per buoy for the 12-buoy ship.

Figure 6-4 shows total deployment time (i.e., port-time plus sea-time) to deploy 275 CNA buoys, 100 DO buoys, and the total 375 buoys. Savings of total deployment time in all CNA regions combined range from 127 days for the 4-buoy ship to 19 days for the 12-buoy ship. For all DO MDZs, combined savings in time range from 183 days for the 4-buoy ship to 41 days for the 12-buoy ship. Figure 6-5 shows average deployment time per buoy planted for all CNA MDZs, all DO MDZs, and for all 375 buoys. Savings in average deployment time per buoy planted for the 12-buoy ship are of the order of 0.07 days per buoy for CNA buoys and 0.22 days per buoy for DO buoys with a resulting average for all buoys of 0.11 days saved per buoy planted. For the 12-buoy ship, this represents a savings of approximately 4% in total time to deploy all 375

Notes:			
1.	Time-to-plant	=	24 hr
2.	Base cost/sea day	=	$5000
3.	Safety factor	=	1.0
4.	Port days/cruise	=	10

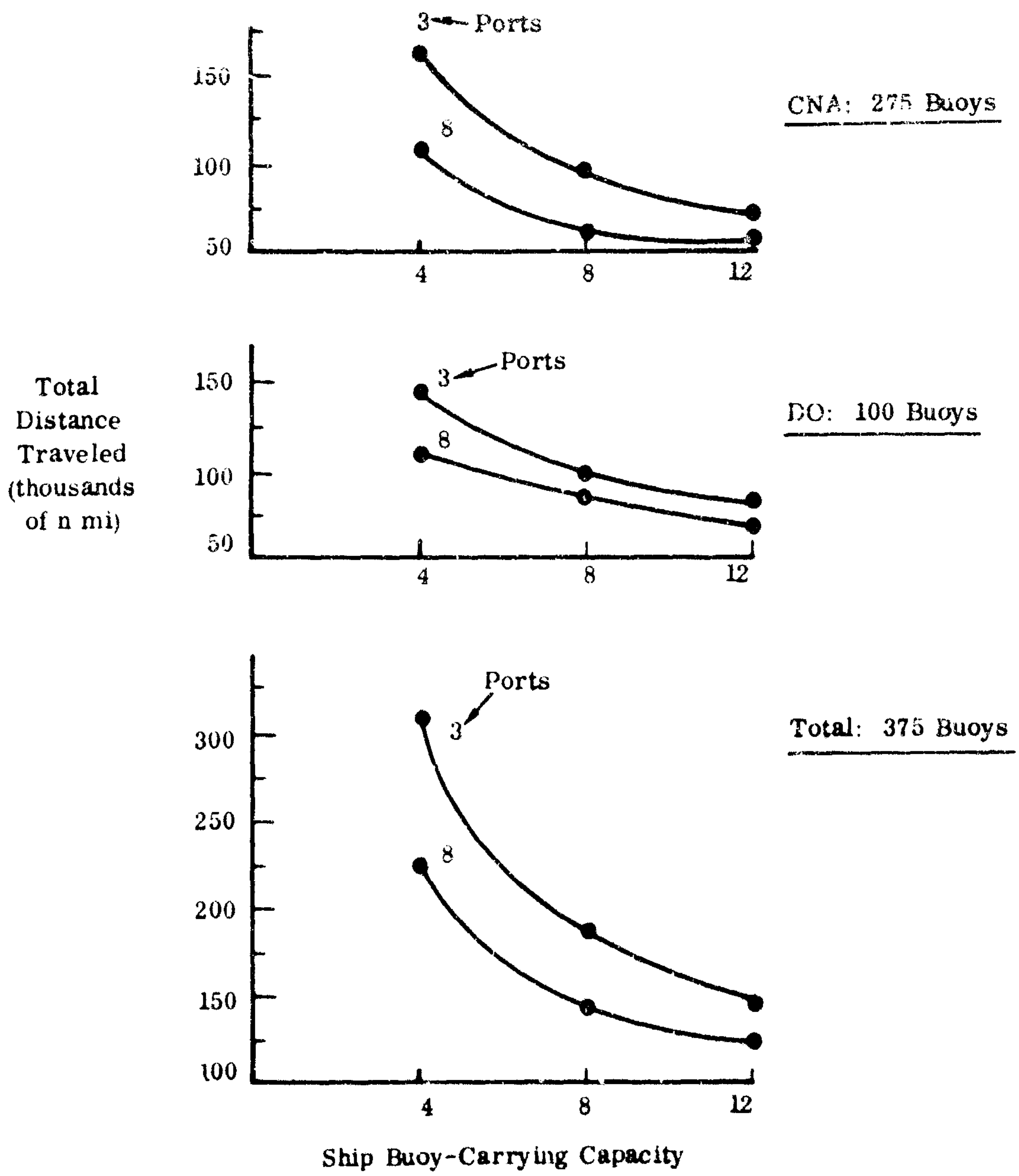


Fig. 6-2. Total distance traveled.

Notes:			
1.	Time-to-plant	=	24 hr
2.	Base cost/sea day	=	\$5000
3.	Safety factor	=	1.0
4.	Port days/cruise	=	10

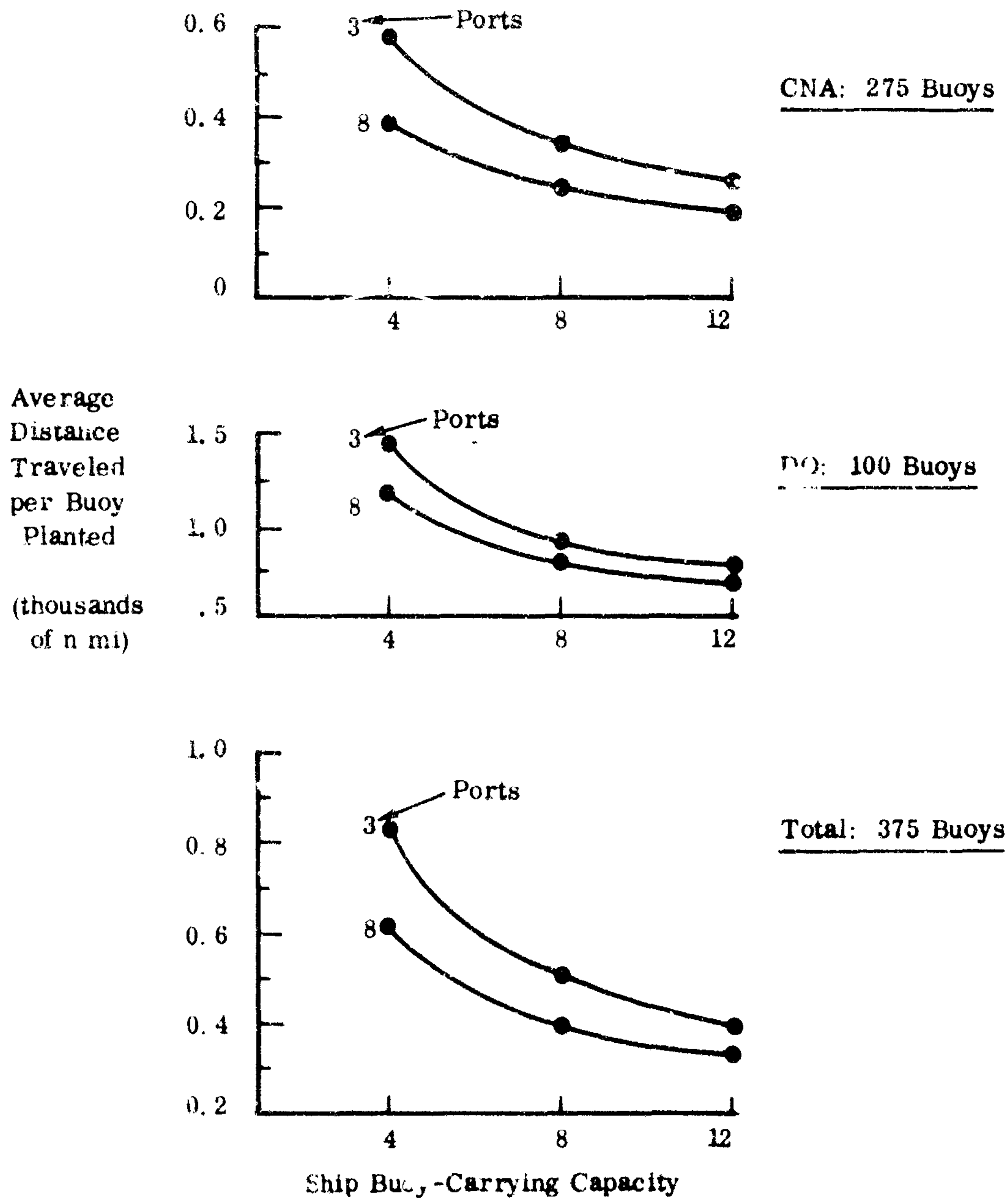


Fig. 6-3. Average distance traveled per buoy planted.

Notes:			
	1.	Time-to-Plant	= 24 hr
	2.	Base Cost/Sea Day	= $5,000
	3.	Safety Factor	= 1.0
	4.	Port Days/Cruise	= 10
	5.	Ship Speed	18 kt

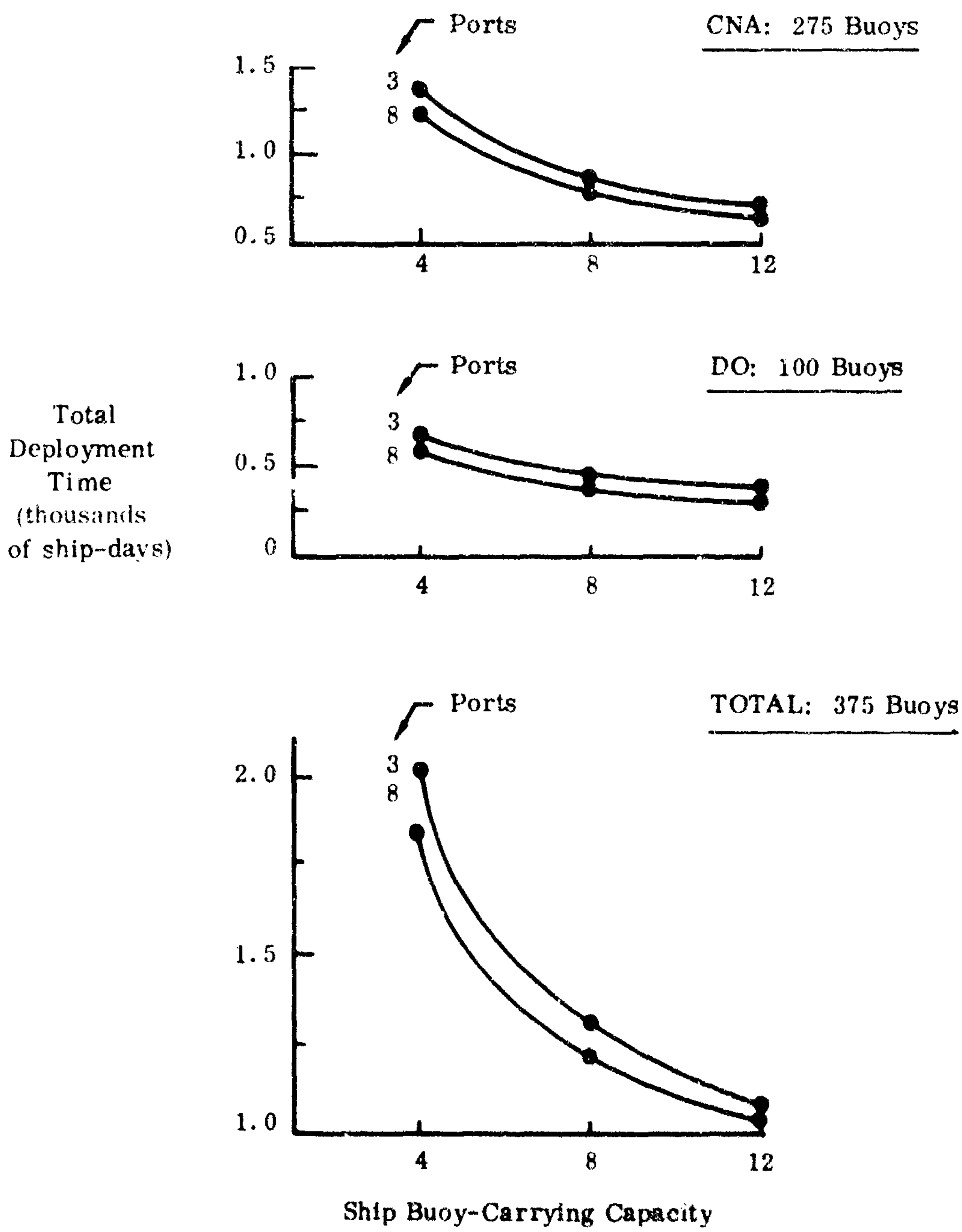


Fig. 6-4. Total deployment time.

Notes:	1.	Time-to-Plant	=	24 hr
	2.	Base Cost/Sea Day	=	$5,000
	3.	Safety Factor	=	1.0
	4.	Port Days/Cruise	=	10
	5.	Ship Speed		18 ft

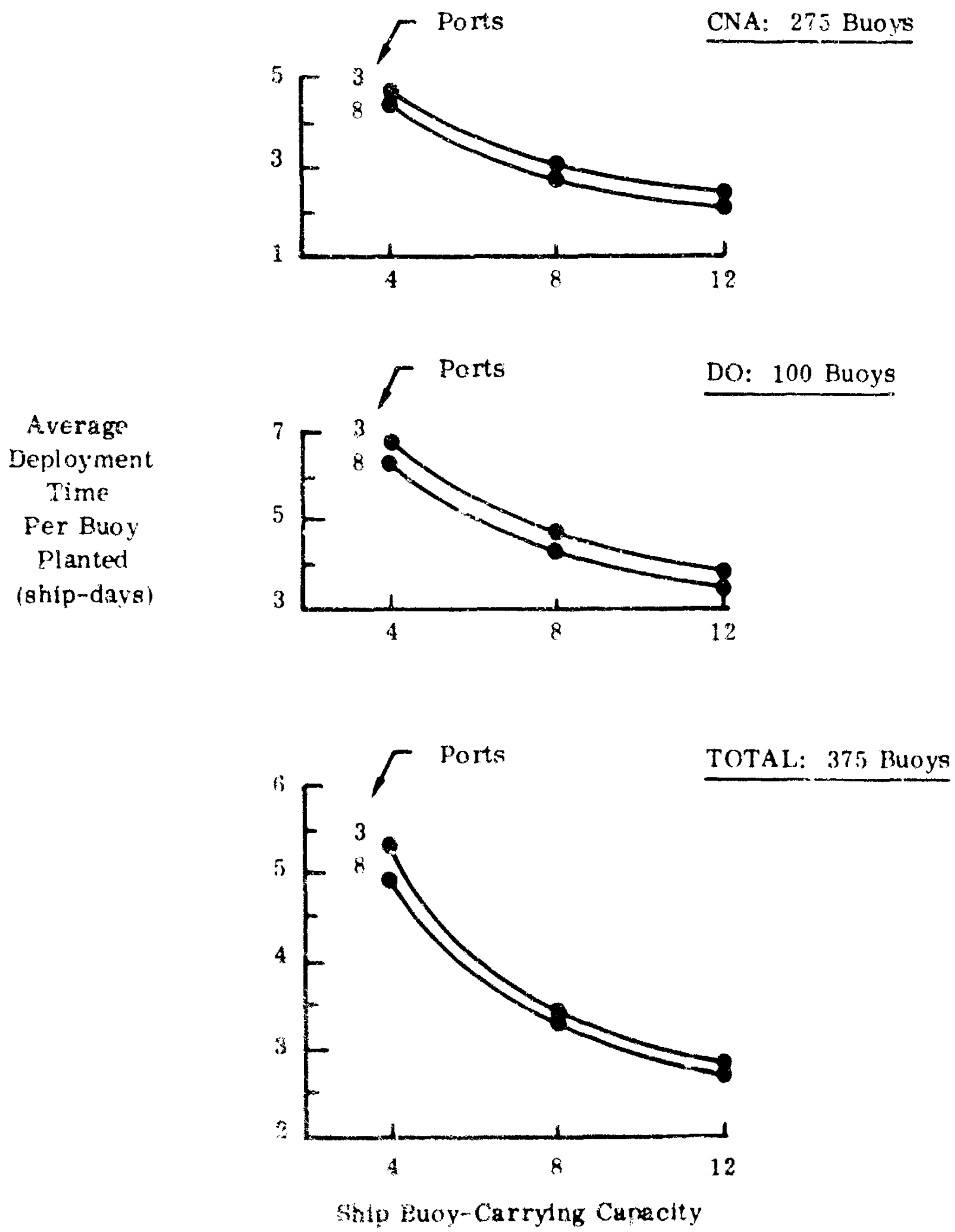


Fig. 6-5. Average deployment time.

buoys. (For the 4-buoy ship, the total saving of 0.49 days per buoy planted represents a savings of approximately 10%.)*

Ship operating deployment cost is in part a function of distance traveled to deploy buoys and also in part a function of time required to deploy buoys. Ship operating deployment cost for deploying 275 CNA buoys, 100 DO buoys and 375 total buoys from three or eight ports is shown in Fig. 6-6 as a function of ship buoy-carrying capacity. Savings in cost due to use of the 8-port configuration for deployment of CNA buoys range from $914,000 for the 4-buoy ship to $234,000 for the 12-buoy ship. For the combined DO MDZs, comparable savings range from $430,000 for the 4-buoy ship to $190,000 for the 12-buoy ship. For all MDZs, combined savings from using the 8-port configuration range from $1,344,000 to $422,000 in going from a 4-buoy to a 12-buoy ship.

Average ship operating cost per buoy planted is shown for CNA, DO and total northern hemisphere regions in Fig. 6-7. Savings in cost per buoy planted in the CNA region range from $3300 to $900 for 4-buoy and 12-buoy ships, respectively; comparable savings of $4300 to $1900 are shown for the combined DO MDZs For all 375 buoys deployed, savings in ship operating cost per buoy planted from use of 8 ports rather than 3 ports, vary from $3600 for the 4-buoy ship to $1130 for the 12-buoy ship.

It is of interest to identify the MDZs in which greatest savings in average ship operating cost per buoy planted, distance per buoy planted, and time per buoy planted are most significant. Comparison by MDZs of average ship operating cost per buoy planted is shown in Fig. 6-8. As expected, average cost per buoy planted is essentially unchanged for the East Coast, West Coast, North Pacific East and North Atlantic

*The reader must bear in mind that all these values are based on a safety factor of 1.0, meaning that deployment time consists of the sum of time-to-plant each buoy, travel time at the stated average speed, and port time (at the rate of 10 days per cruise). Obviously, a safety factor of 1.0 allows for no time lost due to bad weather or other contigencies. Thus, actual time incurred in deployment might be about 10 to 30 percent greater than the values cited (safety factor of 1.1 to 1.3).

Notes: 1. Time-to-plant = 24 hr
2. Base cost/sea day = $5000
3. Safety factor = 1.0
4. Port days/cruise = 10
5 Ship Speed = 18 kt

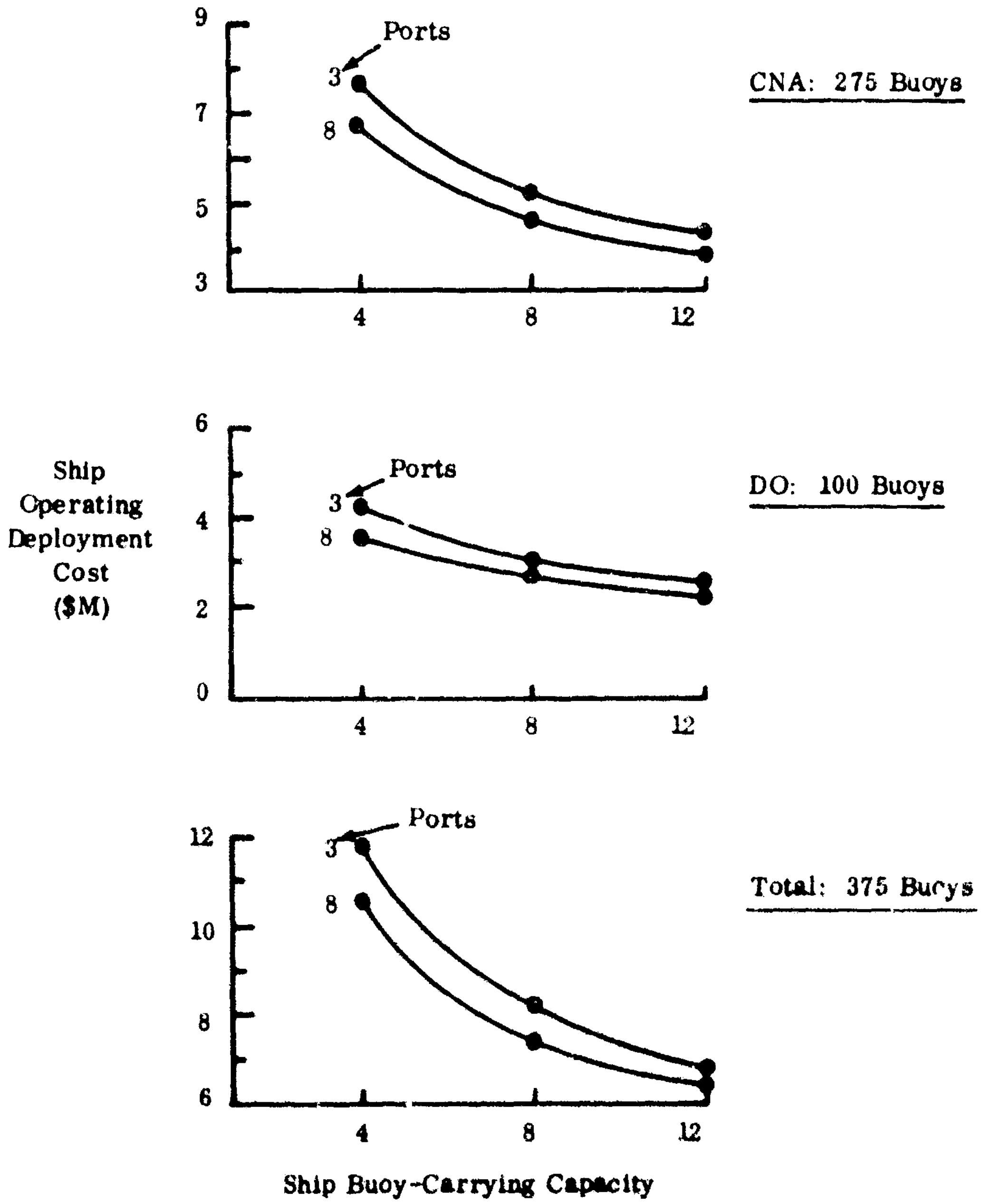


Fig. 6-6. Ship operating deployment cost.

Notes:				
	1.	Time-to-plant	=	24 hr
	2.	Base cost/sea day	=	$5000
	3.	Safety factor	=	1.0
	4.	Port days/cruise	=	10
	5.	Ship Speed		18 kt

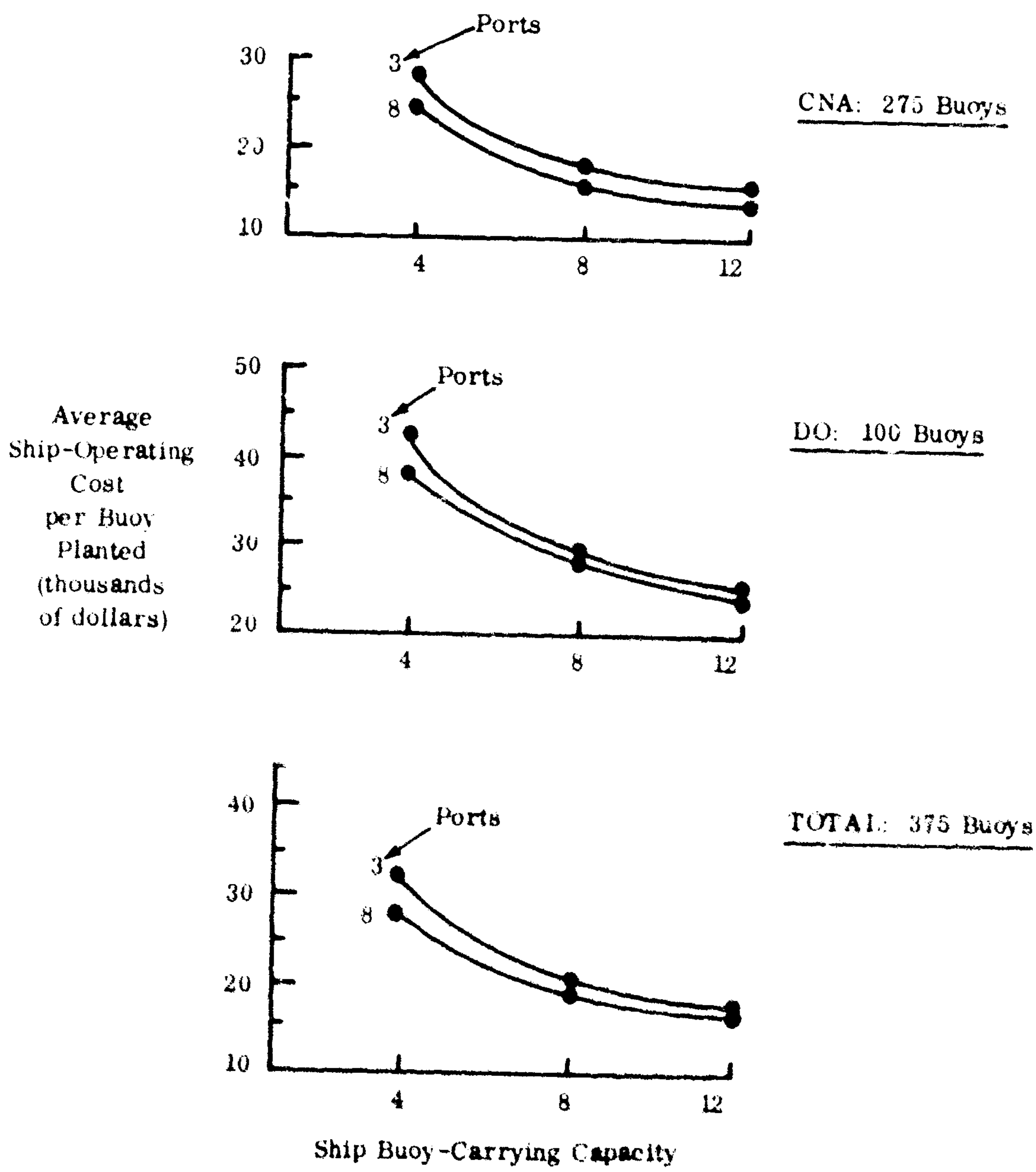


Fig. 6-7. Average ship-operating deployment cost per buoy planted.

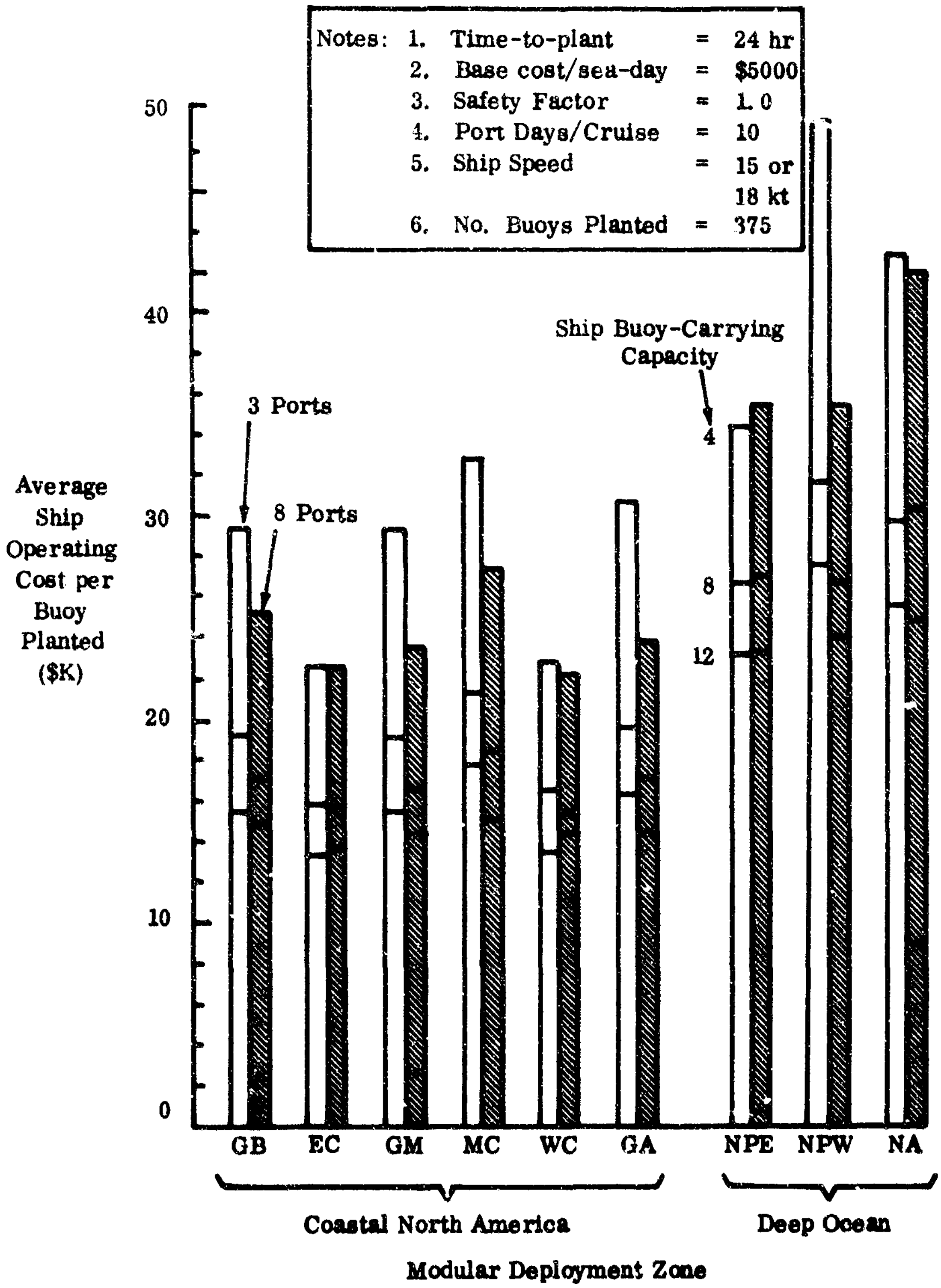


Fig. 6-8. Average ship operating cost per buoy planted.

MDZs.* The greatest improvement in average ship operating cost per buoy planted occurs as also expected in the North Pacific West MDZ. For the 12-buoy ship operating from Guam, that improvement is $3600, whereas savings in average cost for all 375 buoys deployed was only $1130. If an 8-buoy ship is used for deployment from Guam in the NPW MDZ, average ship operating cost per buoy deployed lowers from $31,700 to $26,500.** Greatest percentage of saving, of course, is indicated for the 4-buoy ship, where the average cost per buoy planted drops from $49,500 to $35,000: i.e., a reduction of $14,500 per buoy and a savings of 41.5%. The difference in average cost per buoy planted in going from the 4-buoy ship to the 12-buoy ship, both operating out of Guam, is $11,500.

As an extreme case to illustrate the effect of properly choosing port and ship buoy-carrying capacity, a saving of $25,500 per buoy deployed is indicated by comparing a 4-buoy ship deploying buoys from Honolulu to the NPW MDZ with a 12-buoy ship operating out of Guam for the same deployment.

The Mexican Coast MDZ represents another MDZ in which high savings might be achieved. Here, San Diego rather than San Francisco has been used as the port of deployment. Average cost per buoy planted using the 12-buoy ship, drops from $17,800 to $15,000, an average saving of $2800 per buoy.

In the Grand Banks and Gulf of Mexico MDZs, use of the 8-port configuration indicates that average savings per buoy planted, using a 12-buoy ship, would be $500 and $1200 respectively. In the remaining 4 MDZs (EC, WC, NPE, and NA), no substantial savings are found, because these MDZs are all served by the same ports that are used in the 3-port configuration.

---

*The interested reader will wonder why there are small differences in average cost to plant for the 8-port and 3-port deployments for the EC, WC, NPE, and NA MDZs. These differences stem from somewhat different cruise strategies being employed and a slightly different total number of buoys deployed, in the case of EC, WC, and NPE MDZs. While the basic philosophy of cruise deployment was the same in all cases, the actual sequence of buoys to be deployed was established independently by two individuals at TRC. There was some interest in determining which person would produce the lowest cost deployments in these three MDZs. It is apparent that the variation in results is extremely small, thus demonstrating the efficiency of the general deployment strategy and statements elsewhere in this report that many different approaches to deployment scheduling are approximately equivalent.

**Comparable figures for the 12-buoy ship are $27,600 to $24,000.

Many of the comments presented above are summarized in Fig. 6-9, which shows the reduction in total distance traveled and average distance traveled per buoy planted, and the reduction in total deployment time and average deployment time per buoy planted, and the reduction in total cost to deploy 375 buoys and the reduction in average cost per buoy planted. The numerical details of the curve shown in Fig. 6-9 have been tabulated for ready reference in Table 6-2.

TABLE 6-2
IMPROVEMENT IN 375-BUOY SYSTEM DEPLOYMENT CHARACTERISTICS: 8-PORT VS 3-PORT

Ship buoy-carrying capacity	Reduction in distance traveled (n mi)		Reduction in min. time to deploy (ship-days)		Reduction in deployment cost ($K)	
	Total	Avg/buoy	Total	Avg/buoy	Total	Avg/buoy
4	82,652	220	183.1	0.49	1,344	3.58
8	39,111	104	77.4	0.21	667	1.78
12	26,867	72	40.8	0.11	422	1.13

Notes:
1. Time-to-plant = 24 hr
2. Base cost/sea day = $5000
3. Safety factor = 1.0
4. Port days/cruise = 10
5. Total buoys deployed = 375
6. Ship speed = 18 kt

6.3 Limitations on the 8-Port Vs 3-Port Buoy Deployment Analysis

The above results have been based on a simple analysis involving distance traveled, time at sea and time in port, base cost per sea-day, and fuel and ship maintenance costs. The savings presented are contingent on the meaningfulness of cost values used, and the acceptability of the safety factor, ship speed, and port time assumptions. Prorated ship construction costs have not been included (had they been included, all costs would have been higher and the savings would have been proportionately greater because the use of 8 ports reduces total time to plant and distance traveled, both of which impact directly on the amount of prorated ship costs that would be allocated to the average cost per buoy planted). No attempt has been made to incorporate transportation costs of moving buoys from depots or manufacturing sites to

Notes:	1.	Time-to-plant	= 24 hr
	2.	Base cost/sea day	= $5000
	3.	Safety factor	= 1.0
	4.	Port days/cruise	= 10
	5.	Total Buoys Deployed	= 375
	6.	Ship Speed	= 18 kt

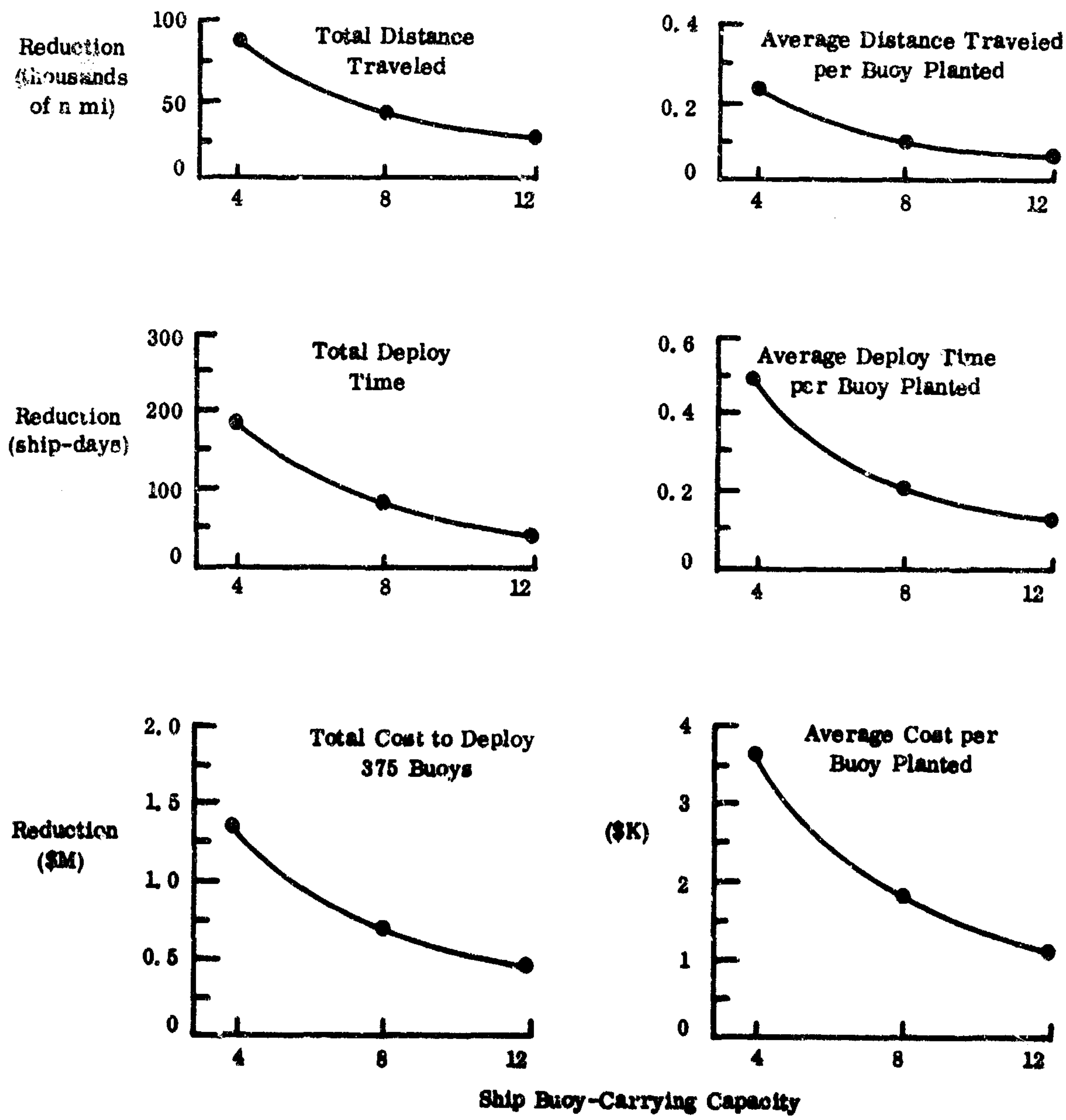


Fig. 6-9. Reduction in deployment characteristics: 8-port vs 3-port.

deployment ports. Nor has any attempt been made to include costs of additional dock-side facilities or on-shore facilities for crews.

6.4 Conclusions

It should be apparent that the 8-port vs 3-port analysis in this section has delineated an upper bound on possible savings and that additional costs such as those outlined in the paragraph above will detract from the possible savings previously presented.

The analysis has provided, however, a basis for preliminary judgment that deployment of buoys in the North Pacific West and the Mexican Coast MDZs should most probably take place from ports such as Guam and San Diego respectively.*

A more thorough analysis must be made to show that apparent marginal savings would justify use of Ketchikan, Galveston, and Boston for deployment of buoys in the Gulf of Alaska, the Gulf of Mexico, and the Grand Banks MDZs, respectively.

In summary, a preliminary judgment that might be derived from this analysis is the following. A 5-port rather than a 3-port buoy deployment (and maintenance) configuration appears to be reasonable for a nine MDZ northern hemisphere data buoy system. However, if the number of buoys to be deployed by the U.S. in the North Pacific West and Mexican Coast MDZs is minimal in comparison to deployments in the other seven northern hemisphere MDZs, then the 3-port deployment configuration (Portsmouth, San Francisco, and Honolulu) appears to be cost effective, unless more detailed analyses show that other potential costs associated with deploying out of other ports are quite small.

The savings that might be accrued from using 8, rather than 3, deployment ports stem in part from reduced fuel costs due to less distance traveled. Table 6-3 shows the distance traveled and fuel costs for an 8-buoy, 15 kt ship ($3.68/n mi) and a 12-buoy, 18 kt ship ($7.01/n mi), for the 3-port and 8-port deployment configurations. Also given in Table 6-3 are the savings in the CNA, DO, and combined CNA and DO regions, along with the savings per buoy planted for all conditions. In brief, for the 8-buoy, 15 kt ship, total fuel costs are $692,000 for 3-port deployment and $548,000 for the

*Further savings might be accrued by deploying from a Mexican port.

8-port case; the saving is $144,000, or $384 saved per buoy planted. For the 12-buoy, 18 kt ship, total fuel costs are $1,046,000 and $858,000 for 3-port and 8-port deployment, respectively. Savings from using 8 ports would be $188,000 or $503 saved per buoy.

TABLE 6-3
FUEL COSTS AND SAVINGS (375-BUOY SYSTEM)

Region	Ship buoy-carrying capacity	Distance traveled (n mi)	Fuel cost ($K)		Fuel cost savings ($K)	Fuel cost savings per buoy planted ($)
			8-buoy ship; 15 kt	12-buoy ship; 18 kt		
3-port:						
CNA	8	94,339	347.2			
	12	71,196		499.1		
DO	8	93,664	344.7			
	12	78,066		547.2		
Total	8	188,003	691.9			
	12	149,262		1,046.3		
8-port:						
CNA	8	66,851	246.0		101.2	368
	12	53,779		377.0	122.1	445
DO	8	82,041	301.9		42.8	428
	12	68,616		481.0	66.2	662
Total	8	148,892	547 [illegible]		144.0	384
	12	122,395		858.0	188.3	503

7.0 ANALYSIS OF TIME-IN-PORT ALTERNATIVES

The number of days that buoy deployment/maintenance ships spend in port following each cruise must be treated as a variable at the time of this study. The NDBS DPO has specified port day ship operating costs at 0.94 of base cost per sea day. Thus, all ship operating costs, except fuel costs, are essentially the same when in port or at sea. Selecting port days per cruise is tantamount to defining a buoy deployment/maintenance policy. For example, if port days per cruise are set at 5, then it would be necessary to provide for a 2-crew mode of operation; and a port and sea routine for "Blue" and "White" crews would have to be established. Conversely, if port days per cruise are set at 20, then it is apparent that for many deployment cruises, the number of days spent in port may exceed the number of days at sea, and the question of crew tasks in port must be considered. With 10 port days per cruise, it is likely that ship loading and crew rest and training will occupy most of the port time. All analyses presented in this report up to this point have used a factor of 10 port days per cruise. (A simple algortihm varying port days between 4 and 10 has been used for ships departing port with less than a full buoy load.)

This section presents in considerable detail the time to deploy buoys, cost to deploy buoys, and the average number of buoys planted per ship-year for time in port per cruise factors of 20 days, 10 days and 5 days. The analysis has been based on the 375-buoy system (75 percent of baseline). Data and results have been obtained for both 3-port and 8-port deployments (i.e., the same port configurations that were used in the previous section). The reader is reminded that throughout this section and this report, a safety factor of 1.0 has been used, thus giving minimum possible costs to accomplish deployment, minimum possible time to accomplish cruise deployment schedules, etc. In actual practice, it may be necessary to allow for up to one-third more time at sea (to account for bad weather and other uncertainties) than would be needed to carry out deployment (or maintenance) under ideal conditions.

7.1 Five, Ten and Twenty Days Port Time Per Cruise: The 3-Port Deployment

Figure 7-1 shows total time to deploy buoys in the six CNA MDZs, the three northern hemisphere DO MDZs, and the time to deploy all buoys in the combined CNA and DO regions. In the CNA region, with a 12-buoy ship, 275 buoys can be deployed

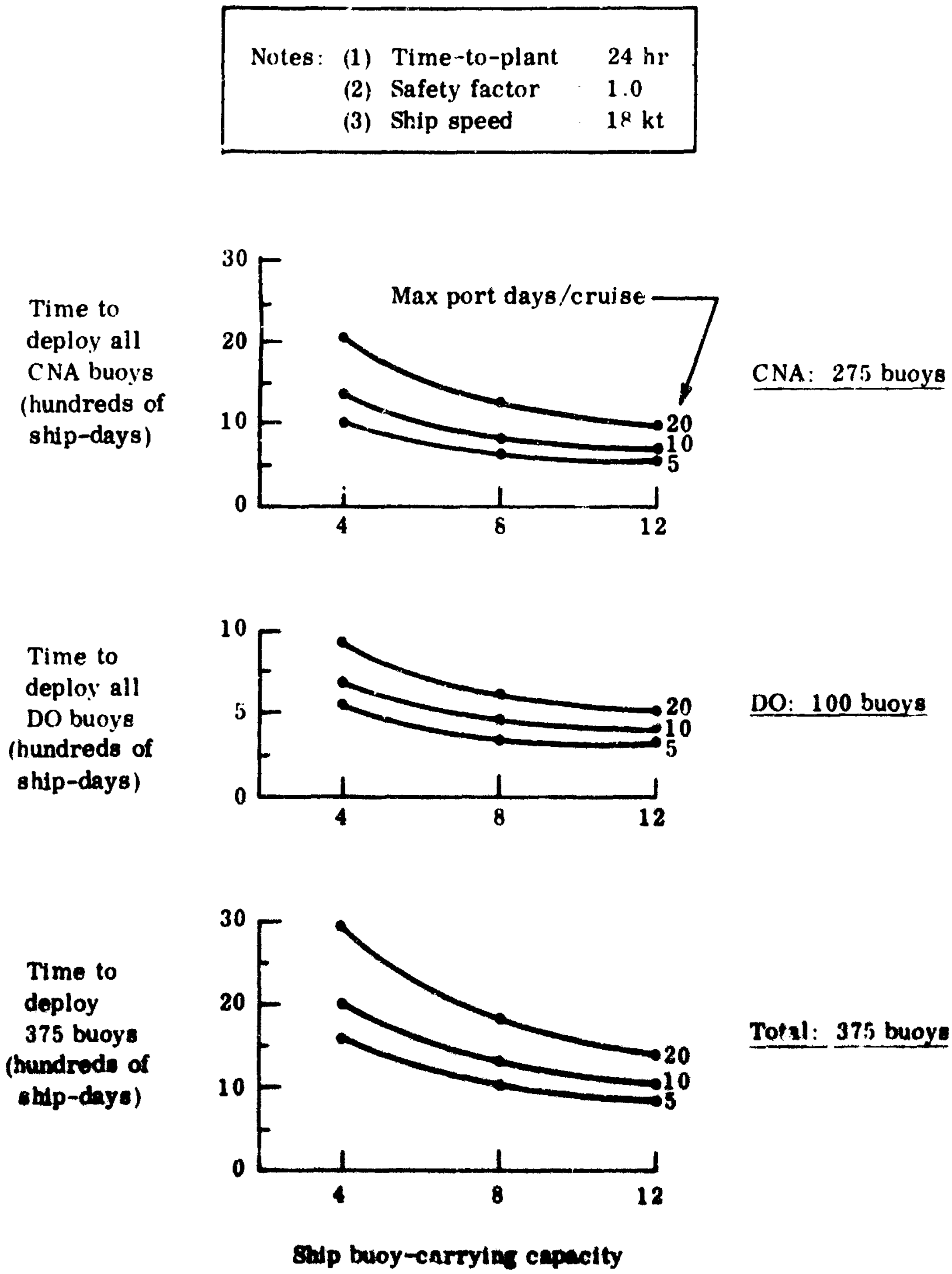


Fig. 7-1. Time to Deploy Buoys (3-Port Deployment)

within a span of approximately 500 to 1,000 ship-days, for port days per cruise ranging from 5 to 20. Total time to deploy is commensurately longer for 8-buoy and 4-buoy ships. In the DO region, 100 buoys can be deployed in approximately 300 to 500 ship-days; again, for port days per cruise in the range of 5 to 20. When both regions are combined, Fig. 7-1 indicates that total deployment time using 5 port days per cruise is about 885 ship-days; it is 1,045 ship-days with 10 port days per cruise; and it is 1,363 ship-days using 20 port days per cruise. With 10 port days per cruise as a base, the 5 port days condition produces a 15 percent reduction in deployment time and the 20-day condition produces a 30 percent increase in time for deployment. (The above values are all based on the following conditions: Ship buoy-carrying capacity of 12, time-to-plant of 24 hours, safety factor of 1.0, and average ship speed of 18 kt.) Figure 7-2 shows the average deployment times in the CNA, DO and northern hemisphere regions commensurate with the previous total times to deploy given in Fig. 7-1. In general, for the 12-buoy ship operating at 18 kt, average time per buoy deployed is between approximately 2.5 and 5 days.

The cost to deploy buoys in the CNA, DO and combined CNA and DO regions is shown in Fig. 7-3. For the 10 port days per cruise and 12-buoy ship condition, total cost of deployment is approximately $6.8 million, resulting from approximately $4.2 million required for CNA and $2.6 million required for DO. Shifting to 5 port days per cruise, and holding other factors the same, results in a reduction in total cost to $5.95 million, and savings of $840,000 (12 percent). Using 20 port days per cruise increases cost to $8.46 million for total deployment, an increase of more than $1.6 million (25 percent). Figure 7-4 presents average cost per buoy planted, based on the costs presented in Fig. 7-3. For the 12-buoy ship and 5 port days per cruise, average cost to plant all 375 buoys can be as low as $15,900 per buoy; for 10 port days per cruise it would be approximately $18,100 per buoy; and for 20 port days per cruise average cost would rise to $22,600 per buoy planted. These values assumed $5,000 base cost per sea day and the other conditions noted above. Explicit values of average ship operations cost per buoy planted are given in Table 7-1.

7.2 Five, Ten and Twenty Days Port Time Per Cruise: The 8-Port Deployment

Figure 7-5 shows the total time to deploy 275 CNA buoys, 100 Deep Ocean buoys, and a total of 375 buoys for the combined CNA and DO regions. When compared to the

Notes: (1)	Time-to-plant	24 hr
(2)	Safety factor	1.0
(3)	Ship speed	18 kt

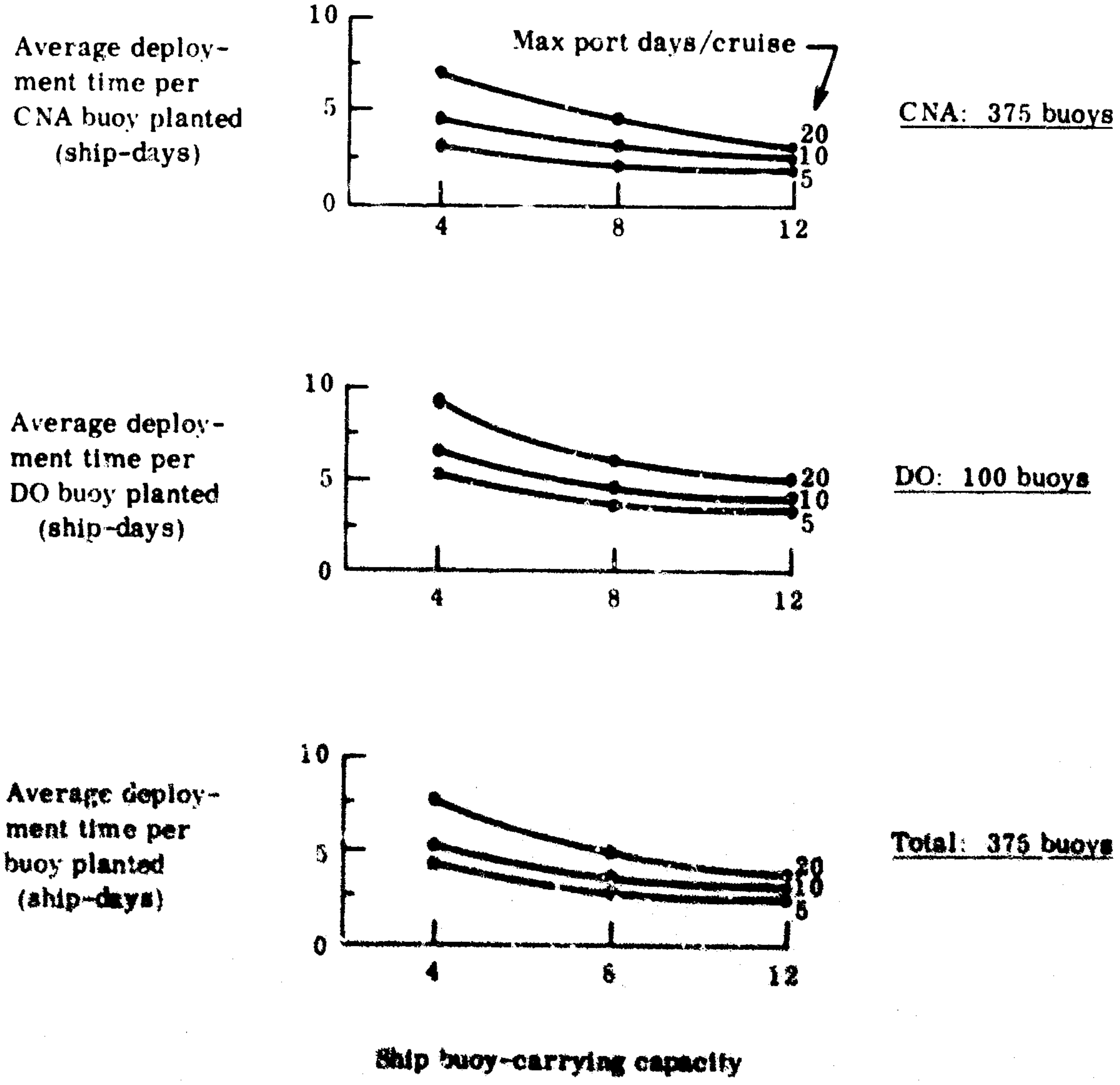


Fig. 7-3. Average Deployment Time Per Buoy Planted (3-Port Deployment)

Notes:			
	(1)	Time-to-plant	= 24 hr
	(2)	Base cost/sea day	= $5000
	(3)	Safety factor	= 1.0
	(4)	Ship speed	= 15 or 18 kt

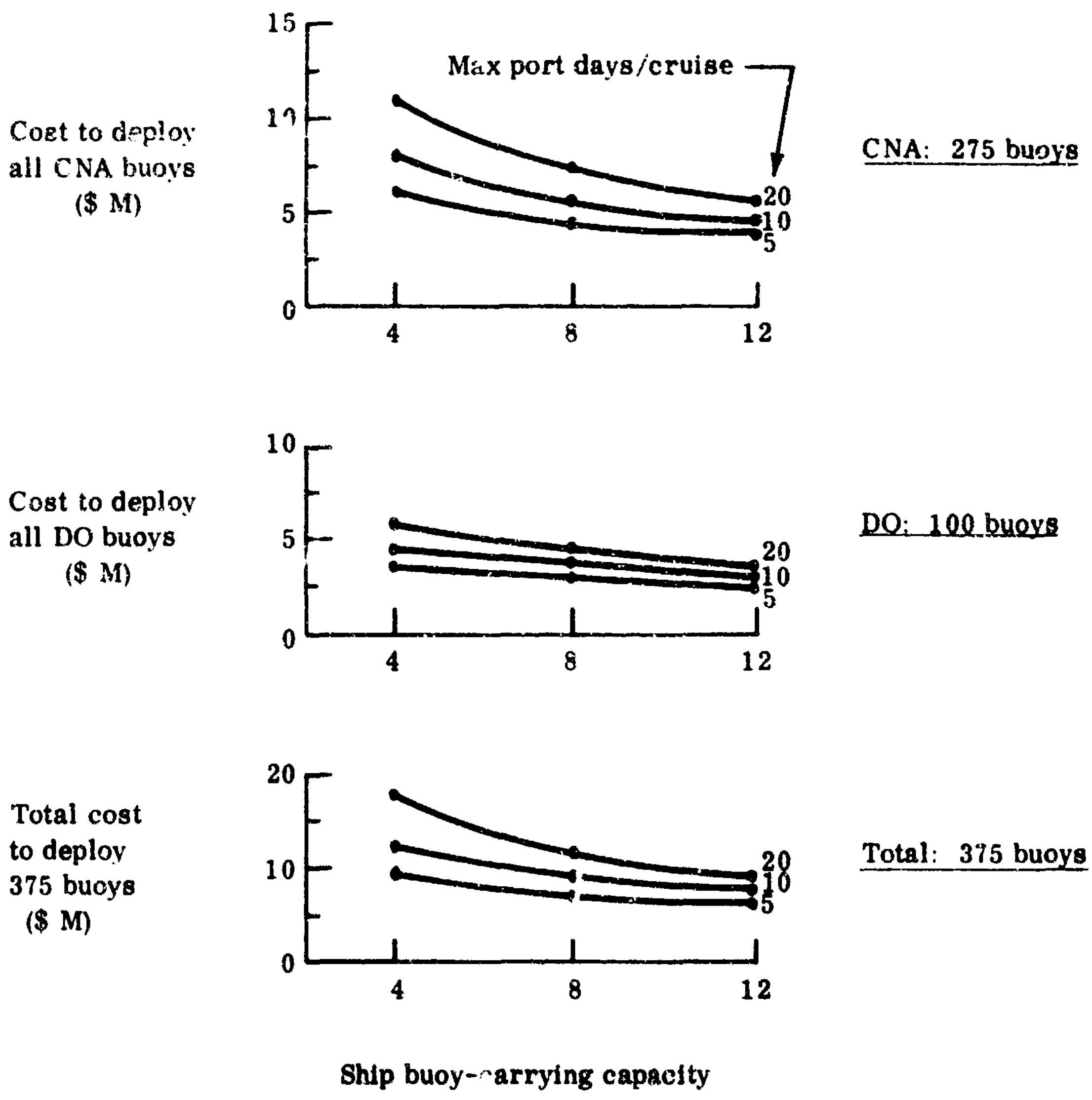


Fig. 7-3. Cost to Deploy Buoys (3-Port Deployment)

Notes:	(1) Time-to-plant	=	24 hr
	(2) Base cost/sea day	=	$5000
	(3) Safety factor	=	1.0
	(4) Ship speed	=	15 or 18 kt

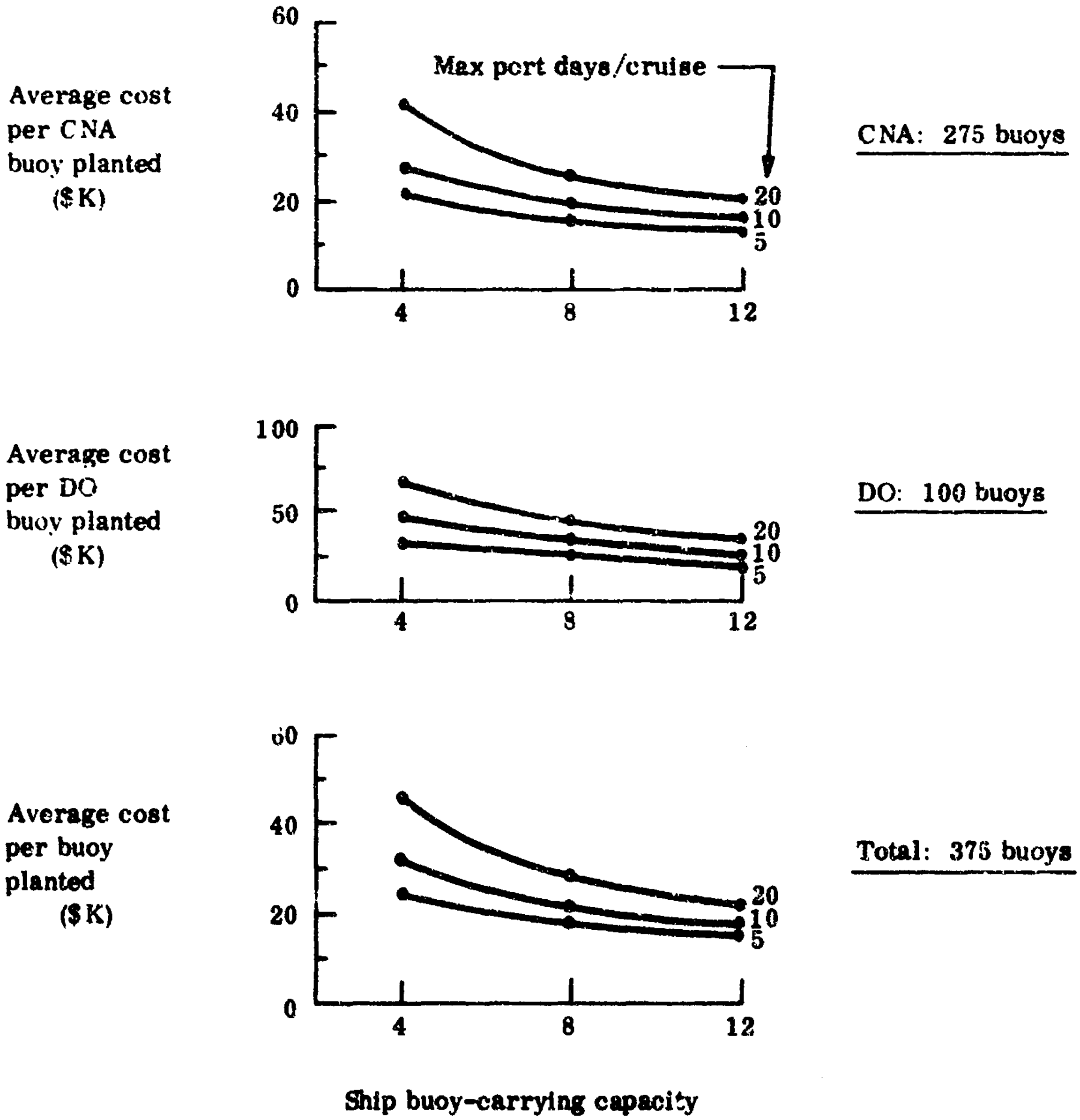


Fig. 7-4. Average Cost Per Buoy Planted (3-Port Deployment)

TABLE 7-1
AVERAGE DEPLOYMENT CHARACTERISTICS

Region	Ship buoy-carrying capacity	Avg. ship operating cost per buoy planted ($K)			Avg. time-to-plant (ship days)			Avg. time in port per buoy planted (ship days)			Avg. time at sea per buoy planted (ship days)
		Maximum port days per cruise			Maximum port days per cruise			Maximum port days per cruise			
		5	10	20	5	10	20	5	10	20	
3-Port											
CNA	4	21.5	27.8	40.3	3.64	4.89	7.41	1.27	2.53	5.05	2.37
	8	15.9	19.3	25.9	2.45	3.09	4.35	0.65	1.30	2.60	1.79
	12	13.1	15.3	19.8	2.04	2.45	3.31	0.44	0.85	1.71	1.60
DO	4	35.9	42.1	64.6	5.63	6.88	9.38	1.25	2.50	5.00	4.38
	8	27.7	31.2	37.7	3.82	4.47	5.72	0.65	1.30	2.55	3.17
	12	23.6	25.9	30.3	3.26	3.71	4.54	0.45	0.90	1.73	2.81
Total	4	25.3	31.6	46.8	4.17	5.42	7.94	1.27	2.52	5.03	2.90
	8	19.1	22.5	29.1	2.81	3.46	4.72	0.65	1.30	2.56	2.16
	12	15.9	18.1	22.6	2.36	2.79	3.63	0.44	0.87	1.71	1.92
8-Port											
CNA	4	18.2	24.5	37.0	3.18	4.44	6.95	1.27	2.53	6.05	1.91
	8	13.9	17.4	23.9	2.22	2.87	4.12	0.65	1.31	2.56	1.56
	12	12.0	14.4	18.9	1.93	2.38	3.23	0.47	0.93	1.78	1.45
DO	4	31.4	37.8	50.3	5.02	6.31	8.81	1.30	2.59	5.10	3.72
	8	25.7	29.4	35.9	3.06	4.30	5.55	0.70	1.40	2.65	2.50
	12	22.3	24.0	29.0	3.11	3.49	4.39	0.45	0.90	1.73	2.66
Total	4	21.7	28.0	40.6	3.67	4.94	7.45	1.28	2.55	5.06	2.39
	8	17.0	20.6	27.1	2.59	3.25	4.50	0.67	1.33	2.58	1.92
	12	14.7	17.0	21.6	2.24	2.68	3.54	0.47	0.92	1.77	1.77

Notes: (1) Time-to-plant = 24 hr
(2) Base cost/sea day = $5000
(3) Safety factor = 1.0
(4) Ship speed = 15 or 18 kt

Notes:	(1) Time-to-plant	=	24 hr
	(2) Safety factor	=	1.0
	(3) Ship speed	=	18 kt

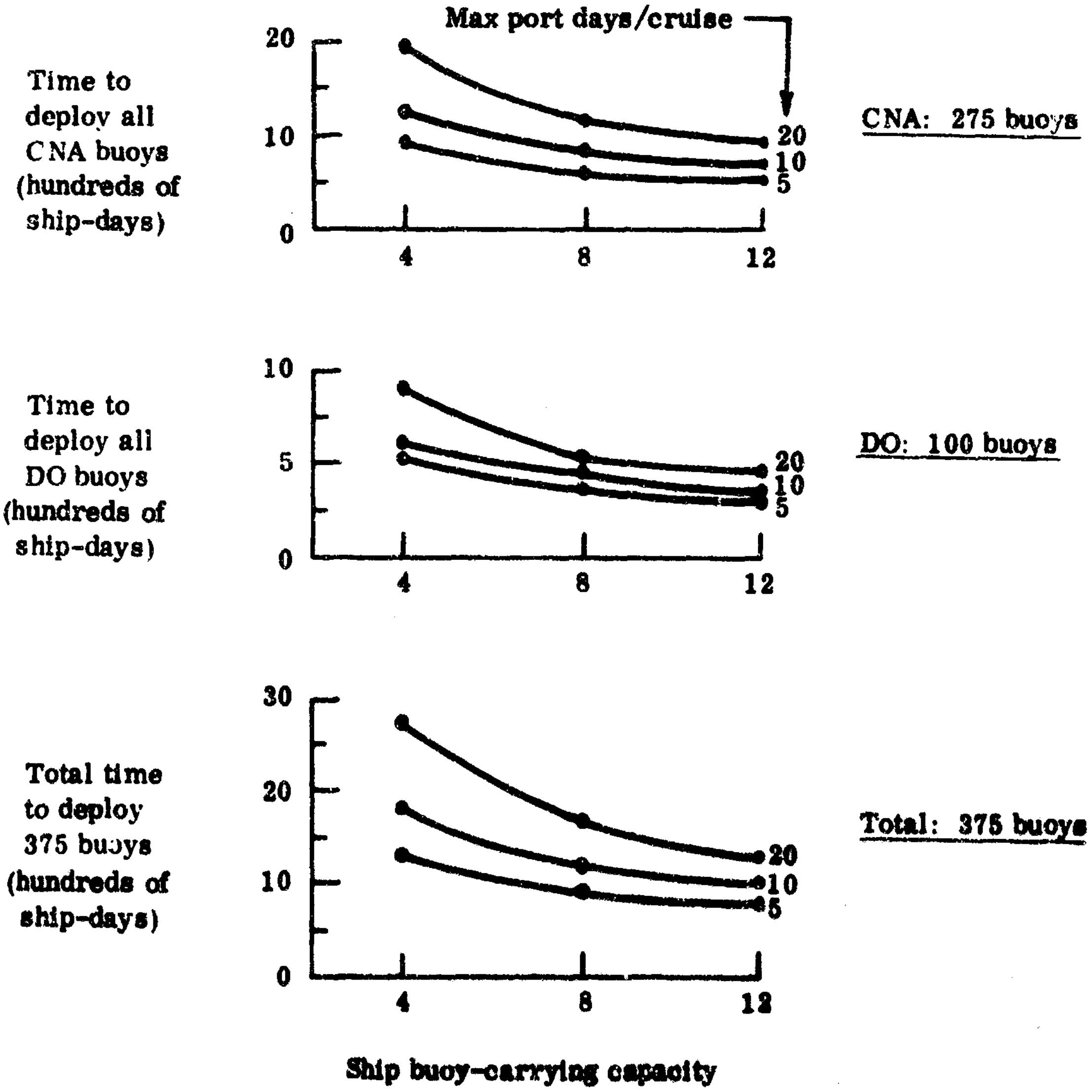


Fig. 7-5. Time to Deploy Buoys (8-Port Deployment)

10 port day results, it is apparent that reducing port days to 5 per cruise also reduces total time to deploy in all ranges approximately 16 percent, i.e., whereas it takes 1,000 ship-days to deploy all 375 buoys with 10 port days per cruise, there is a reduction to 840 ship-days for 5 port days per cruise. (These figures hold for a time-to-plant of 24 hours, a safety factor of 1.0, and an average ship speed of 18 kt.) This 16 percent improvement is only slightly better than the 15 percent improvement noted for the 3-port deployment.

Comparing the 20 port days per cruise to the 10 port days per cruise, it is seen that the total time to deploy increases by approximately 30 to 50 percent. Thus, while the 12-buoy ship requires 1,000 ship-days for total deployment based on 10 port days per cruise, the same ship would require more than 1,300 days, using 20 port days per cruise. A 4-buoy ship under similar conditions would require 1350, 1800, and 2800 ship-days for deployment for port days per cruise of 5, 10, and 20, respectively, as seen from Fig. 7-5.

Figure 7-6 gives average deployment time per buoy planted based on the total times to deploy shown in Fig. 7-5. Average time to deploy all 375 buoys from a 12-buoy ship varies from 2.24 days per buoy planted using 5 port days per cruise, to 2.68 days per buoy planted for 10 port days per cruise, and 3.54 days per buoy planted for for 20 port days per cruise. Using 10 port days per cruise as a reference, there is a reduction of 16.4 percent in going to the 5 port day per cruise condition, and a 31.3 percent increase when using the 20 port days per cruise condition. These figures apply to the 12-buoy ship, a safety factor of 1.0, 24 hours time-to-plant, and an average ship speed of 18 kt.

Figure 7-7 shows cost to deploy in CNA, DO, and all 375 buoys, using a base cost per sea-day of $5,000. Cost to plant all 375 buoys for the 10 port days per cruise is approximately $6.4 million. (It was $6.8 million for the 3-port deployment.) Use of 5 port days per cruise results in a savings of approximately $840,000, and use of 20 port days per cruise increases deployment costs by $1,730,000. The decrease is about 13 percent and the increase is about 26 percent. Figure 7-8 gives average cost per buoy planted for the total costs shown in Fig. 7-7. Explicit values of average cost are found in Table 7-1. It is seen that for the 12-buoy ship and combined CNA and DO regions, the average ship-operating cost per buoy planted ranges from $14,700 to $21,600, for 5 and 20 port days per cruise, respectively.

Notes: (1) Time-to-plant = 24 hr
(2) Safety factor = 1.0
(3) Ship speed = 18 kt

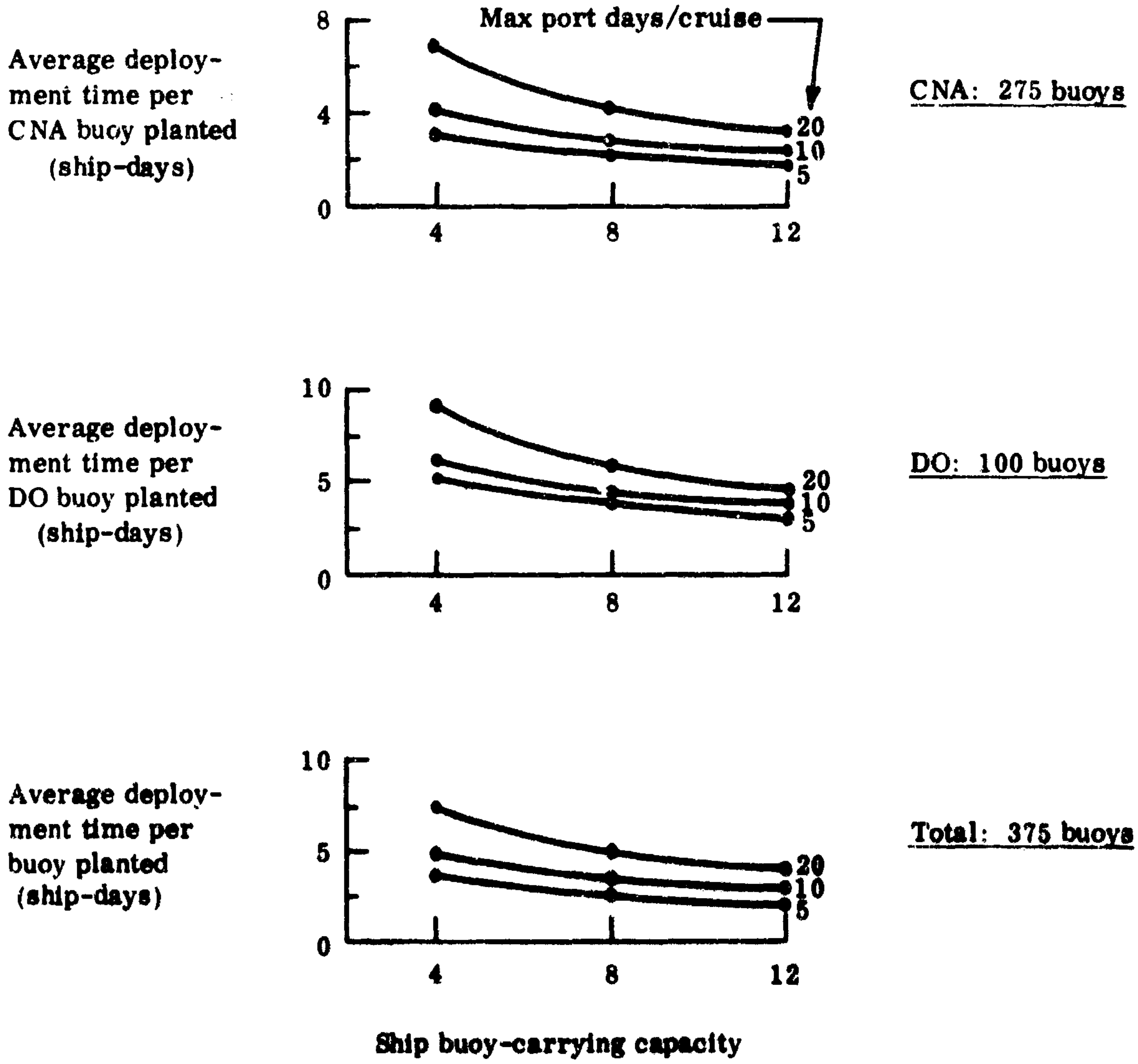


Fig. 7-6. Average Deployment Time Per Buoy Planted (8-Port Deployment)

Notes	(1)	Time-to-plant	= 24 hr
	(2)	Base cost/sea day	= $5000
	(3)	Safety factor	= 1.0
	(4)	Ship speed	= 15 or 18 kt

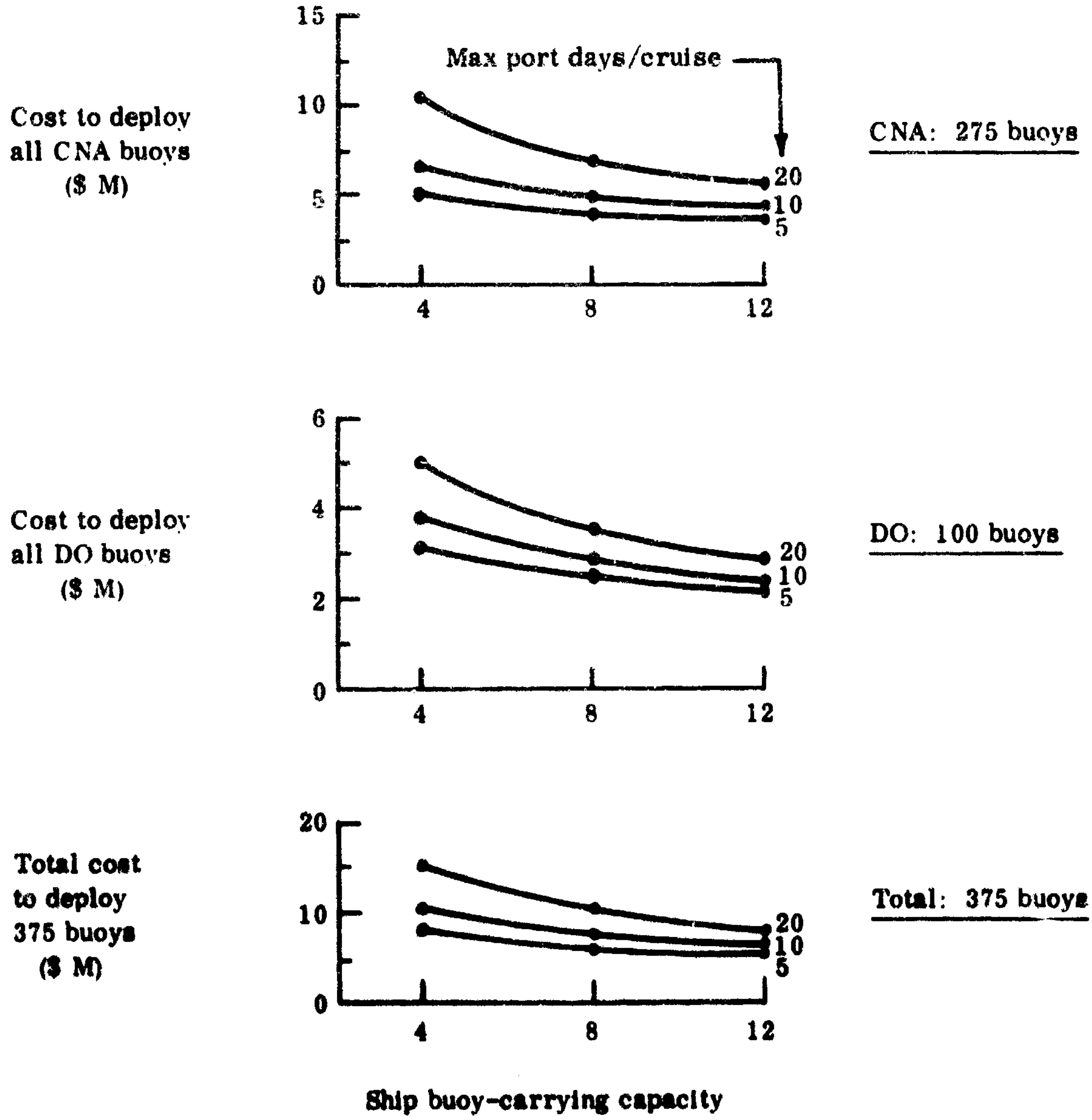


Fig. 7-7. Cost to Deploy Buoys (8-Port Deployment)

Notes:	(1) Time-to-plant	=	24 hr
	(2) Base cost/sea day	=	$5000
	(3) Safety factor	=	1.0
	(4) Ship speed	=	15 or 18 kt

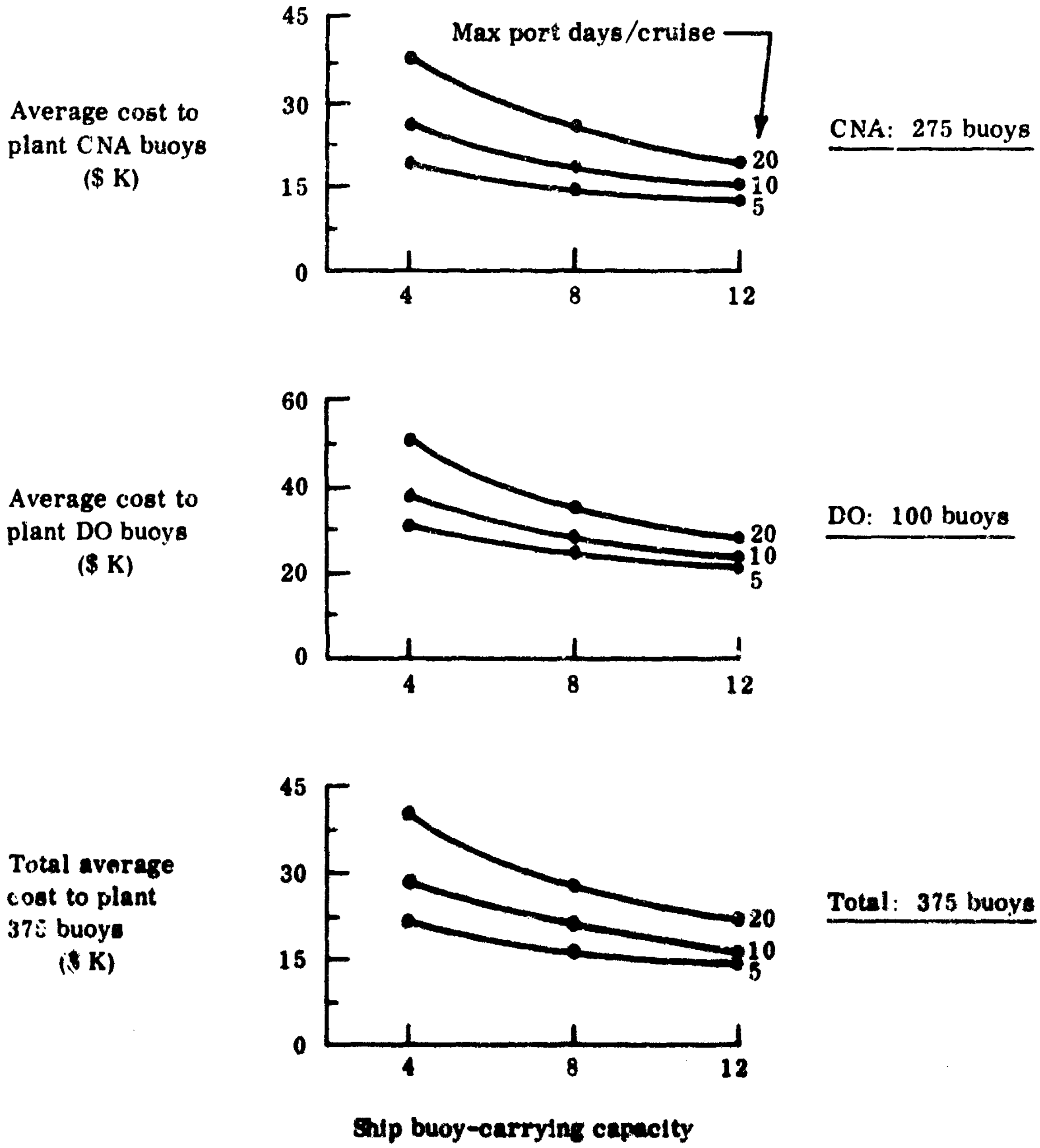


Fig. 7-8. Average Cost Per Buoy Planted (8-Port Deployment)

7.3 Detailed Port-days Analysis for the Twelve-buoy Ship

The preceding 3-port and 8-port analyses make clear the advantage of using the 12-buoy, 18 kt ship. A more detailed comparison of the results of varying port days per cruise is shown in Figs. 7-9 through 7-12. Both 3-port and 8-port data have been plotted.

Figure 7-9 shows the comparison of time to deploy buoys in the CNA, DO and combined CNA and DO regions. Deployment time in CNA ranges from approximately 560 to 910 days for the 3-port case, and 530 to 890 days for the 8-port case, for 5 and 20 port days per cruise, respectively. The corresponding intermediate 10 port day values are 675 and 656 days. For the DO region, the deployment times for 5, 10, and 20 port days are 326, 371 and 454 for the 3-port configuration; and 311, 349 and 439 for the 8-port configuration. The summation of deployment times gives 886, 1,045 and 1,363 days for the 3-port case; and 840, 1,004 and 1,328 days for the 8-port case. The purpose in delineating the data plotted in Fig. 7-9 is to emphasize the lower bound on the time required (ship-days) to effect deployment of the 375-buoy system.

Assuming 335 operating days per ship, for the 12 buoy, 18 kt ship, the total deployment could be carried out by three ships in one year under the 3-port, 5-port days per cruise condition with a safety factor of 1.14 (i.e., 1,004/886). Using 3 ships and the 8-port, 10-port days per cruise condition, the entire deployment could be carried out with a safety factor of 1.0. Of course, it must be held in mind that under the conditions specified, the three ships would spend a total of 375 days in planting the buoys and they would accumulate a total of about 330 to 360 days in port. Thus, on the average, each of the three ships would be traveling to and from port and buoy locations and from buoy location to buoy location less than one-third of the time. If 20 port days per cruise becomes the standard mode of operation, it is evident that it would take four ships to carry out deployment in one year.*

*It has been noted elsewhere that with on-board refurbishment of buoys, it is quite possible that more than 12 buoys could be maintained on a cruise. Thus, deployment might be made from 8 ports to get the task done as quickly as possible, and maintenance might take place from as few as 3 to as many as 6 ports. There are many potentially economical combinations of ports, cruise schedules, and port days per cruise that might show that three ships could satisfactorily handle the entire 375-buoy system. It is quite clear, however, that 375 buoys is approximately the upper limit for accomplishing deployment in one year by three 12-buoy, 18 kt ships.

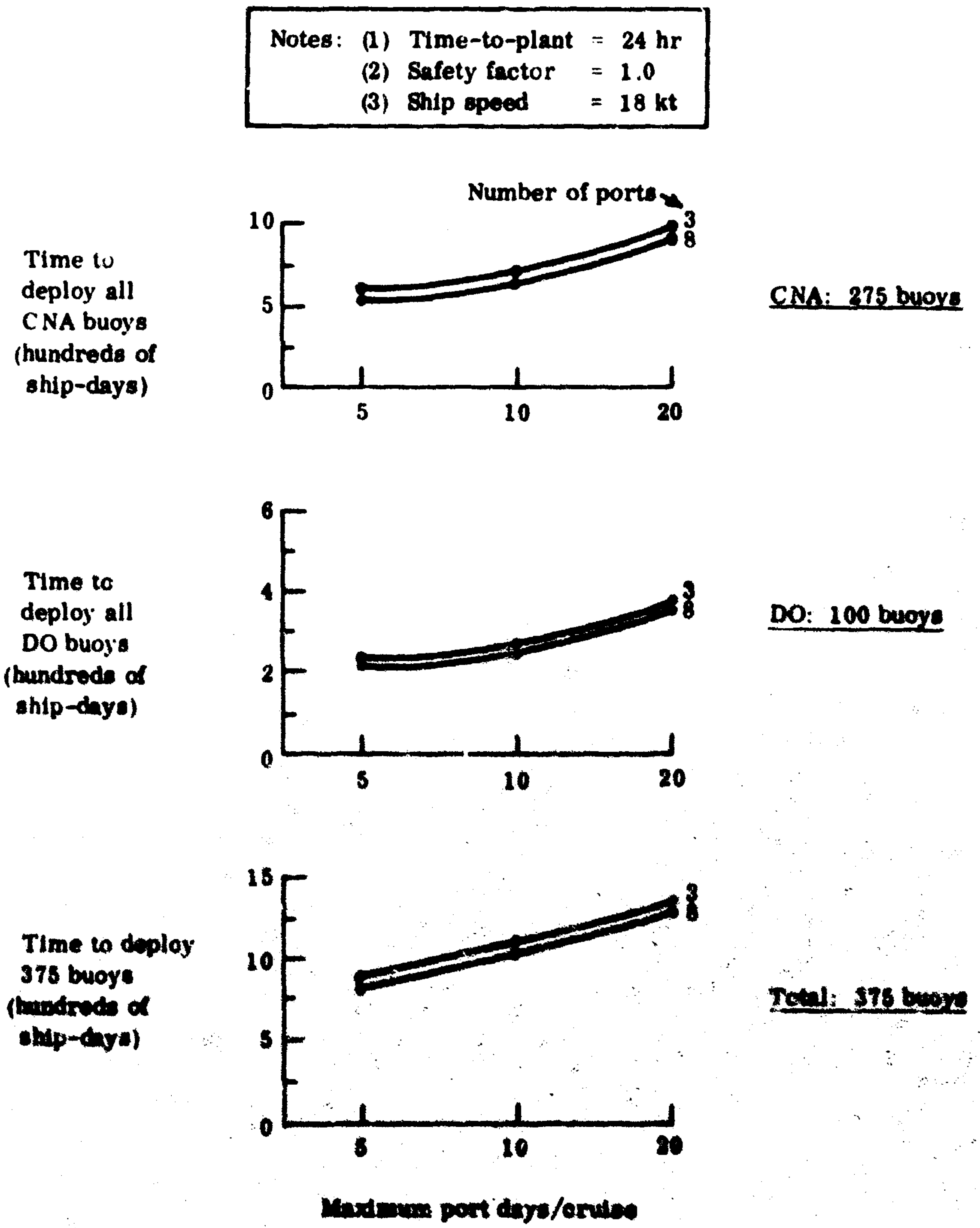


Fig. 7-9. Time to Deploy Buoys (12-Buoy Ship)

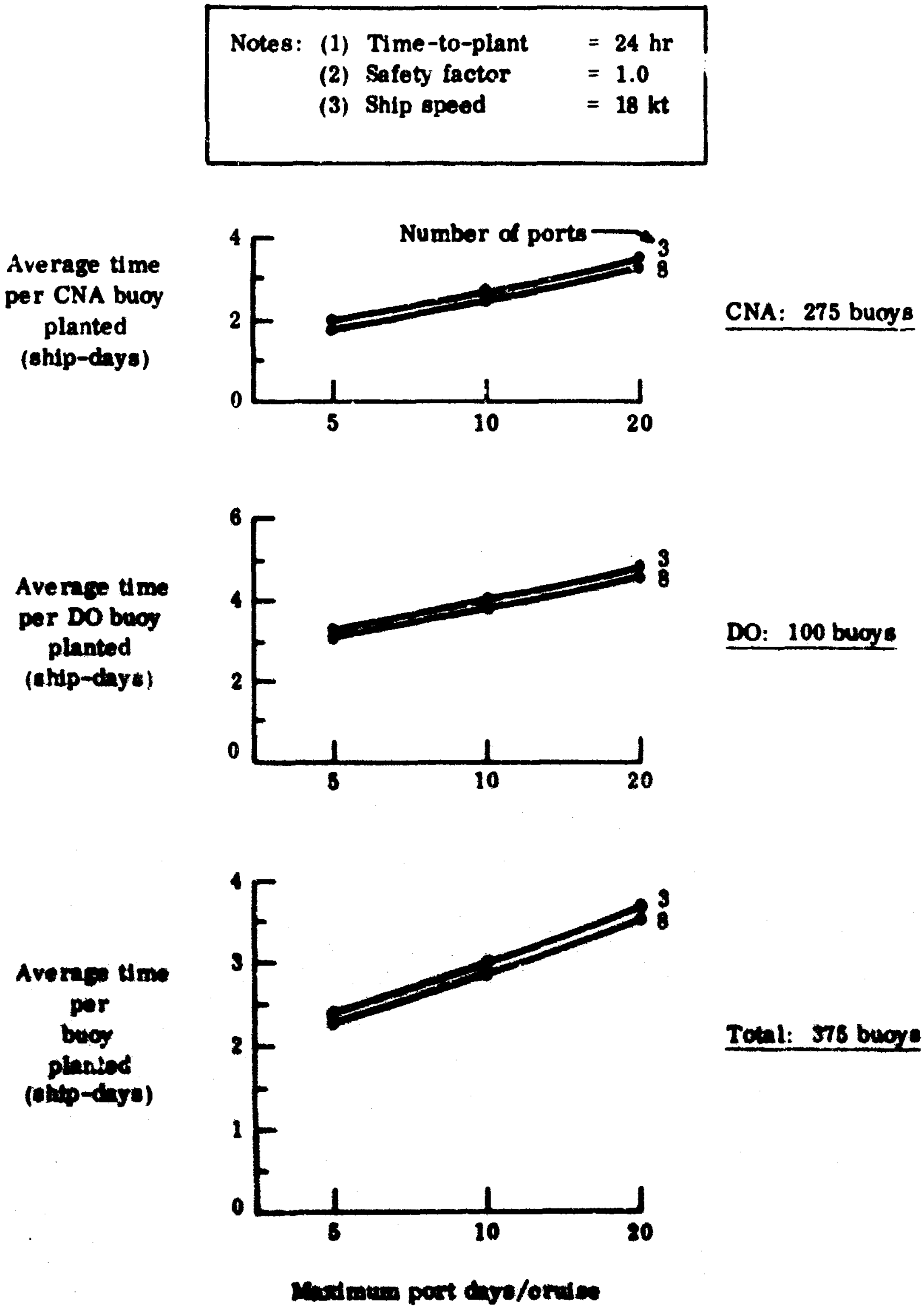


Fig. 7-10. Average Deployment Time Per Buoy Planted (12-Buoy ship)

Notes: (1) Time-to-plant = 24 hr
(2) Base cost/sea day = \$5,000
(3) Safety factor = 1.0
(4) Ship speed = 15 or 18 kt

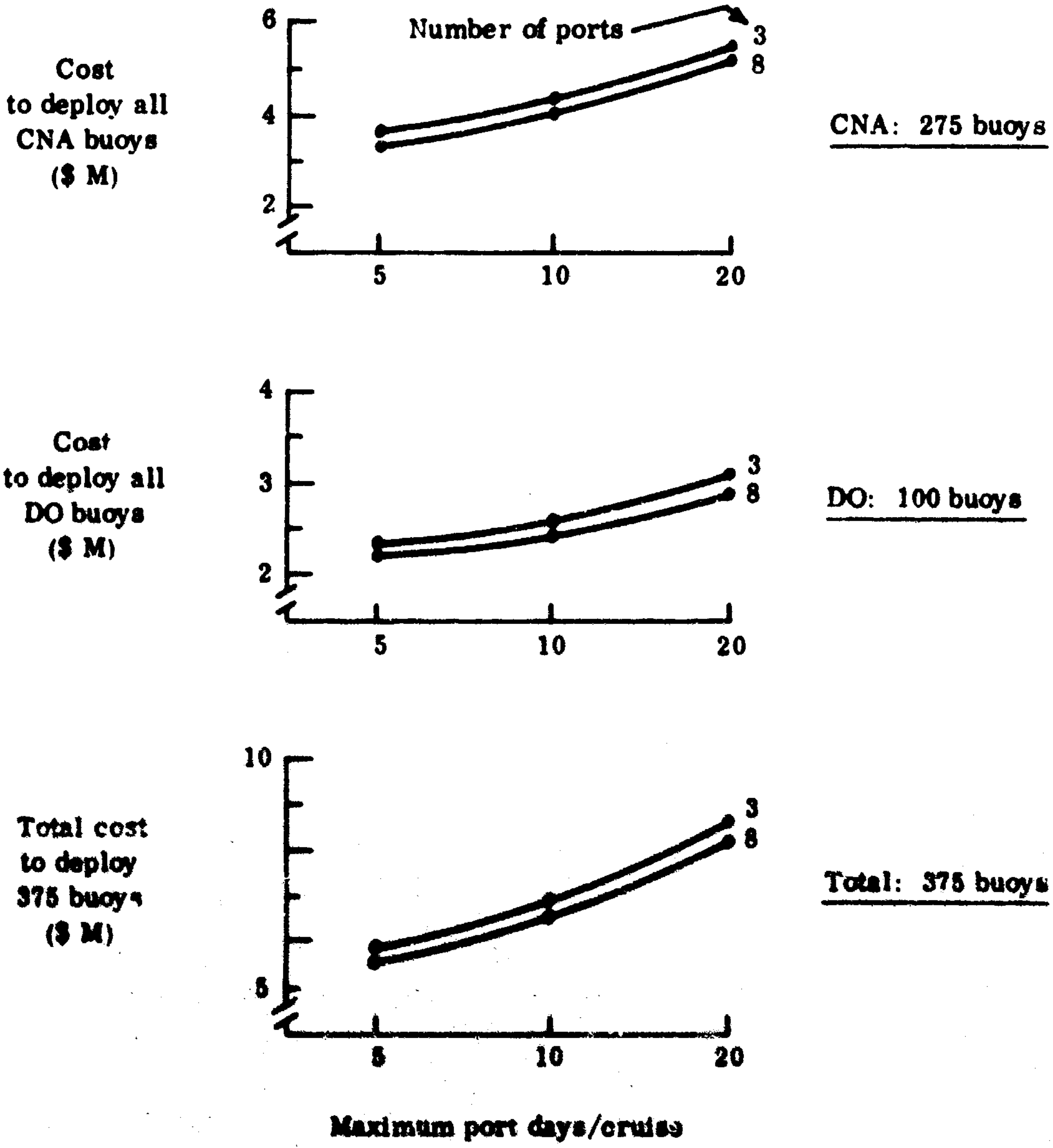


Fig. 7-11. Cost to Deploy Buoys (12-Buoy Ship)

Notes:	(1)	Time-to-plant	= 24 hr
	(2)	Base cost/sea day	= $5,000
	(3)	Safety factor	= 1.0
	(4)	Ship speed	= 15 or 18 kt

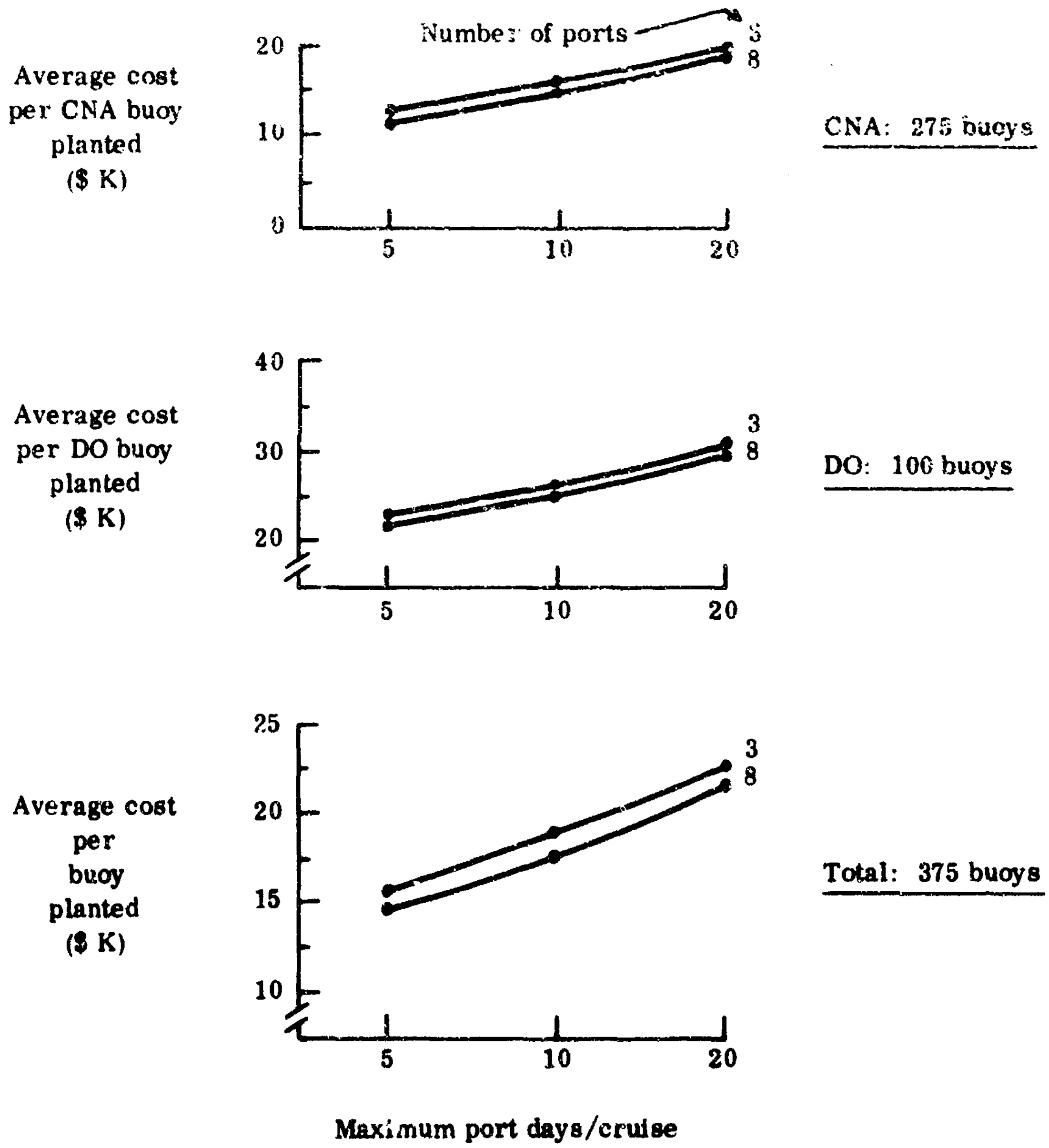


Fig. 7-12. Average Cost Per Buoy Planted (12-Buoy Ship)

Figure 7-10 gives average time to plant each buoy for CNA, DO and the combined CNA and DO regions. For the 3-port condition, in CNA the values are approximately 2.04, 2.45 and 3.3 days for 5, 10 and 20 port days per cruise. In DO, the corresponding average times are 3.25, 3.7 and 4.5. For the combination of CNA and DO regions, the values are 2.36, 2.8 and 3.63 days. Use of the 8-port condition gives only minor improvements: 1.95, 2.38 and 3.23 days in CNA; 3.1, 3.5 and 4.4 days in DO; and 2.24, 2.68 and 3.54 days for the combined regions. Again, the numerical values associated with the plotted curves are presented to stress the minor overall improvement in going from the 3-port to 8-port configuration, and to highlight the considerable differences compared by the range of 5 to 20 port days per cruise. It should be held in mind that for all average time to plant values, one day (24 hours) of the value given is attributable to the task of deploying the buoy and a <u>safety factor of 1.0</u> has been used.

In general, developing a technique to complete deployment in 12 hours or less would produce a greater overall improvement in operations than shifting from a 3-port to 8-port configuration, or shifting from 10 to 5 port days per cruise. In short, there would be a large payoff in keeping deployment time while on station to the minimum practicable—possibly in the range of 6 to 12 hours.

Total ship operating cost to deploy buoys is presented in Fig. 7-11. For the combined CNA and DO regions, using three ports, total ship operating cost ranges from \$5.95 million to \$8.46 million, in going from 5 to 20 port days per cruise.* The 10 port day cost value is \$6.8 million. The corresponding 8-port range of values if \$5.53 million to \$8.09 million, with \$6.4 million for the 10 port day value. Clearly, going from 3 ports to 8 ports produces a \$400,000 savings, before other costs are factored in. Converting from 10 to 5 port days reduces ship operating costs by about \$800,000 (before deducting the additional costs of the alternate crew); changing from 10 to 20 port days increases costs by about \$1.6 million. Shifting from 10 to 20 port days per cruise is essentially (but not exactly) equivalent to using the 10 port day per cruise condition with a safety factor of about 1.3.

The average ship operating cost per buoy planted is shown in Fig. 7-12. The supporting data are tabulated in Table 7-1 and need not be repeated here. All average costs shown in Fig. 7-12 lie somewhere in a range bounded by \$12,100 per buoy and

*Loosely interpreted, this suggests that \$6 million is probably a lower bound on the cost of deploying the 375-buoy system, and \$9 million is an upper bound on cost.

$30,000 per buoy. Average costs for the 10 port days per cruise condition are in an inner range of $14,400 per buoy (CNA, 8-ports) to $25,900 per buoy (DO, 3-ports).

In summary, an effort has been made here to delineate in greater detail the general and relative nature of savings or increased cost of operations due to variation in port days per cruise, using two different deployment port configurations. In instances where savings have been shown, it must be clearly recognized that in all cases the act that presumably creates the savings also produces secondary costs that have not been considered in this analysis. Thus, in actual practice, there would be little likelihood of achieving all of the savings indicated.

7.4 Relationship of Port Days to Sea Days

To contribute to overall system cost-effectiveness, the operational schedule for a major buoy tending ship must provide a high average rate of useage, for buoy deployment/maintenance ships represent major capital investments. Port time—while obviously necessary for refueling, taking on supplies, on-loading and off-loading data buoys, etc.—may also be representative of capital investment used uneconomically.*

The three figures presented in this subsection—Figs. 7-13 through 7-15—show graphically the relative average port days and average sea days per buoy deployed in the CNA region (Fig. 7-13), in the DO region (Fig. 7-14), and in the combined CNA and DO regions (Fig. 7-15). The data used for these graphs is found in Table 7-1. All three figures are based on 24 hrs time-to-plant, average ship speed of 18 kt, a safety factor of 1.0, and use of the 3-port deployment.

In each figure the average time at sea per buoy planted is a fixed function of ship buoy-carrying capacity. Maximum port days per cruise is the principal variable. Using average time at sea per buoy planted as a reference, the average port time in the CNA region is 27.5%, 53%, and 106% of the time at sea, for 5, 10, and 20 port days per cruise, using the 12-buoy ship. The percentages would be higher for an 8-buoy or 4-buoy ship.

*The port time referred to here is defined as scheduled ship time in port between scheduled cruises. It does not include the approximately 60—75 days required every two years for dry dock overhaul of the ship.

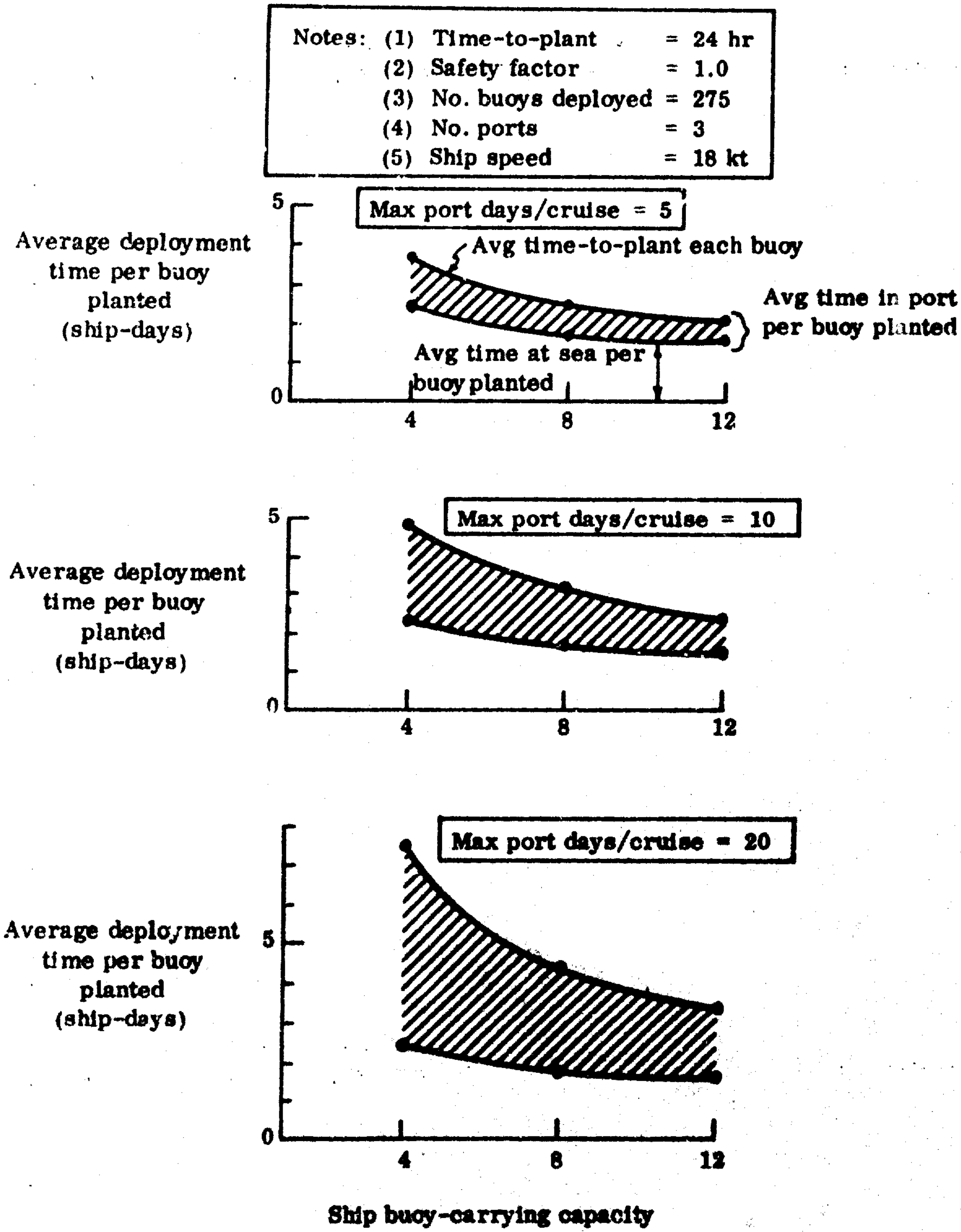


Fig. 7-13. Comparison of Coastal North America Average Deployment Time Per Buoy Planted

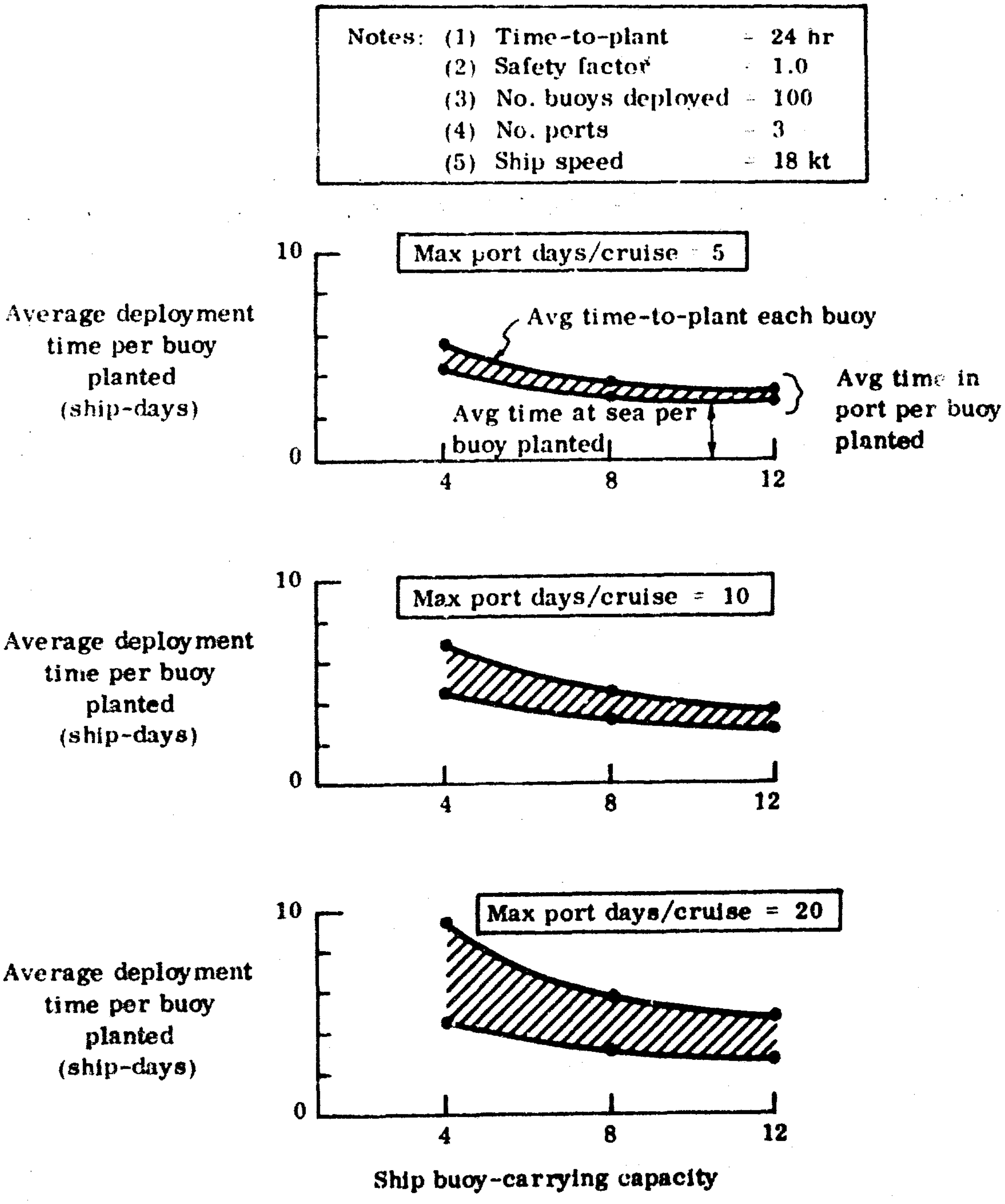


Fig. 7-14. Comparison of Deep Ocean Average Deployment Time Per Buoy Planted

Notes:			
	(1)	Time-to-plant	24 hr
	(2)	Safety factor	1.0
	(3)	No. buoys deployed	375
	(4)	No. ports	3
	(5)	Ship speed	= 18 kt

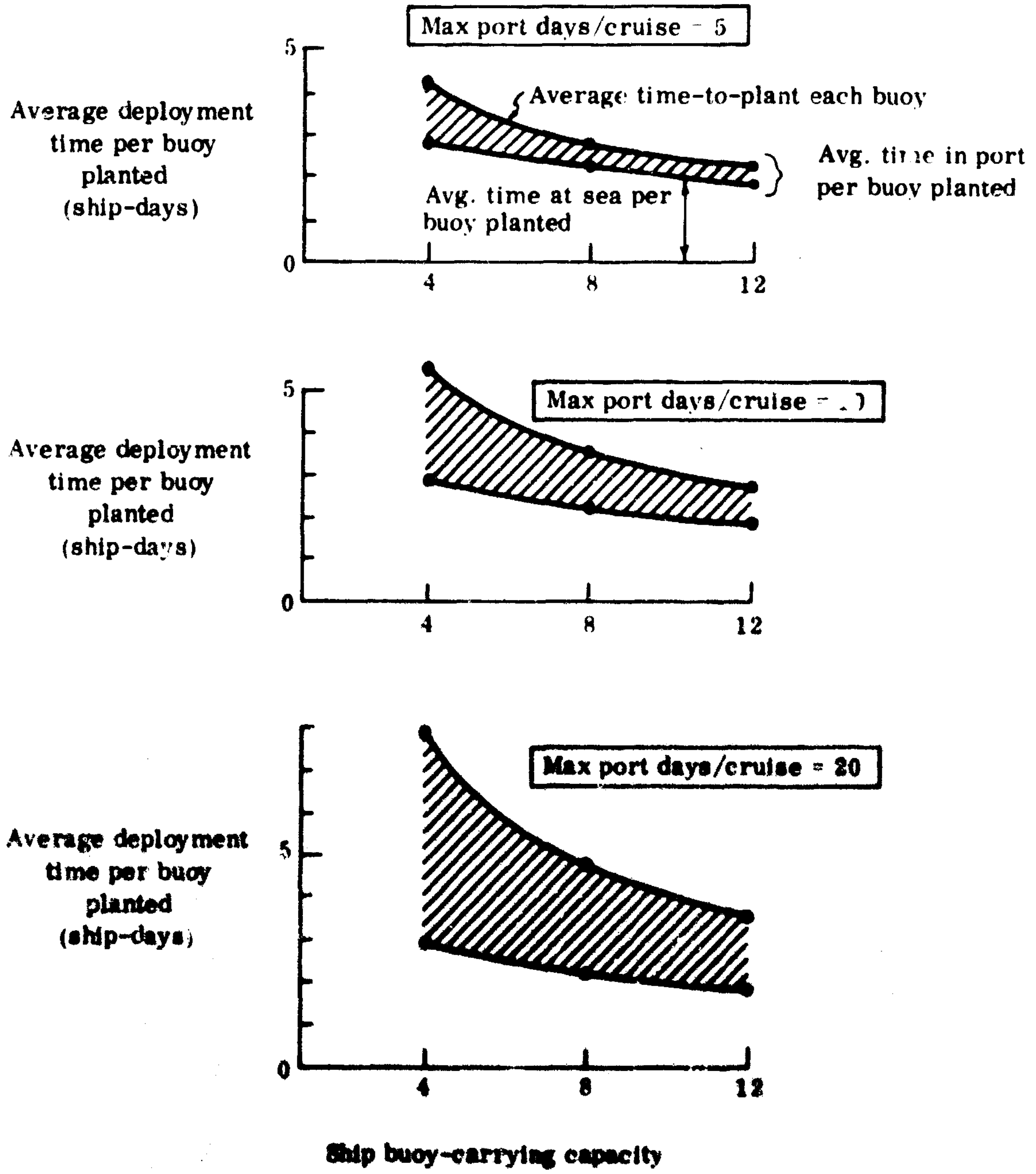


Fig. 7-15. Comparison of Northern Hemisphere Average Deployment Time Per Buoy Planted

For the DO region—again using the 12-buoy ship—cruises are longer in duration (some exceed the the desired 22.5 day limit) and the percentage of average time in port per buoy planted, relative to average time at sea, is less than in CNA: 16%, 32%, and 61.5% for 5, 10, and 20 maximum port days per cruise.

For the combined CNA and DO regions, and using the 12-buoy ship and other conditions noted previously, the percentage of average time in port per buoy planted, relative to average time at sea per buoy planted is 23%, 45%, and 89% for 5, 10, and 20 port days per cruise.

In all cases, the use of a ship with a smaller buoy-carrying capacity results in a higher ratio of port days to sea days, because deployment cruises are generally of shorter duration due to a smaller number of buoys being deployed.

To summarize, for the 12-buoy, 18 kt ship, scheduling 20 port days per cruise results on the average over both CNA and DO in essentially equal amounts of time at sea and in port (using a safety factor of 1.0). Correspondingly, scheduling 10 port days per cruise results in port time being about one-third to one-half the time at sea for DO and CNA respectively, with the average over both regions being slightly less than half. Using 5 port days per cruise brings the ratio of port days to sea days to 0.275 for CNA, 0.16 for DO, and 0.23 for both regions combined.

It might be noted that these results are in line with what should have been expected. The fact that the buoy deployment/maintenance simulation and cost model confirms what appears to be intuitively true does not diminish the usefulness of the results. Rather, it places more confidence in the use of relatively simple planning factors, always an important goal in the use of a system simulation model.*

*It is nice to have intuition supported, but that support has not always been forthcoming in this study. For example, the reduction in time and ship operating cost to deploy buoys by going from a 3-port to an 8-port deployment configuration was expected to be of the order of 15—20%, before other costs are included. The fact that the reduction was of the order of 5—6% on an overall basis did not support the initial intuitive answer. Obviously, simulation models are also important to help disabuse analysts and planners of their falsely held notions.

7.5 Effect of Port Days on Average Number of Buoys Planted per Ship-year

Deployment (and maintenance) of data buoys can, under most economical conditions, take place only in a quantum (or, modular) sense. Simply put, there is an upper bound on how much a deployment/maintenance ship can accomplish in a unit period of time. To do substantially more requires acquisition of another ship. Thus, a fundamental metric (or, planning factor) that should evolve from a study such as this is the deployment (maintenance) capability of a ship of specified characteristics. A convenient way of expressing deployment capability is in terms of the average number of buoys planted per ship-year. Here, the guidance of the NDBS DPO has been followed and an average ship-year has been assumed to be 335 days.

Buoy deploying capability of a ship is a function of ship buoy-carrying capacity, ship speed, total distance to be traveled to deploy all buoys (which in turn is a function of buoy and port locations), time-to-plant each buoy, and port days per cruise. The desired values of buoys planted per ship-year follow directly from the average time to deploy buoys, discussed previously in this section.

Average number of buoys planted per ship-year as a function of ship-buoy-carrying capacity, maximum port days per cruise, and for 3-port and 8-port configurations is given in Table 7-2. These data are graphically presented in Figs. 7-16, 7-17, and 7-18, for the 3-port, 8-port, and 12-buoy ship respectively.

The figures (and the table) support the conclusion that the 100 DO buoys in the 375-buoy system might be deployed in <u>about</u> one ship-year, total. But it is obvious that it would probably be necessary to use Guam as a deployment port in the North Pacific West MDZ, and port days per cruise might have to be close to 5 days.*

In CNA two 12-buoy 18-kt ships could deploy all 275 buoys from the 3-port configuration within a year, under the 10-port days per cruise, <u>safety factor of 1.0</u>, and 24 hr time-to-plant conditions. A more desirable situation of fewer hours to plant, fewer port days per cruise, and more deployment ports would permit deploying the 275 buoys within a year with a safety factor greater than 1.0. There are obviously a number of

*Not obvious from these values and graphs is the fact that a number of cruises would exceed 22.5 days, even at the 18-kt ship speed. Of course, if time-to-plant could be reduced to 12 hr rather than 24 hr, then more desirable deployment schedules might be planned.

TABLE 7-2
AVERAGE NUMBER OF DATA BUOYS PLANTED PER SHIP-YEAR (335 DAYS)

Region	Ship buoy-carrying capacity	Average maximum number of buoys planted per ship-year			Average sensitivity (Buoys planted/ship-year per port day/cruise)
		Maximum port days/cruise			
		5	10	20	
3-Port					
CNA	4	92	69	45	-3.2
	8	136	108	77	-3.9
	12	164	137	101	-4.2
DO	4	60	49	36	-1.6
	8	88	75	59	-1.9
	12	103	90	74	-1.9
Total	4	80	62	42	-2.5
	8	119	97	71	-3.2
	12	142	120	92	-3.3
8-Port					
CNA	4	105	75	48	-3.8
	8	151	117	81	-4.7
	12	174	141	104	-4.7
DO	4	67	53	38	-1.9
	8	93	78	60	-2.2
	12	108	96	76	-2.3
Total	4	91	68	45	-3.1
	8	129	103	74	-3.7
	12	150	125	95	-3.7

Notes: (1) Time-to-plant = 24 hr
(2) Safety factor = 1.0
(3) Ship speed = 18 kt

Notes:	(1)	Time-to-plant	24 hr
	(2)	Safety factor	1.0
	(3)	Ship speed	18 kt

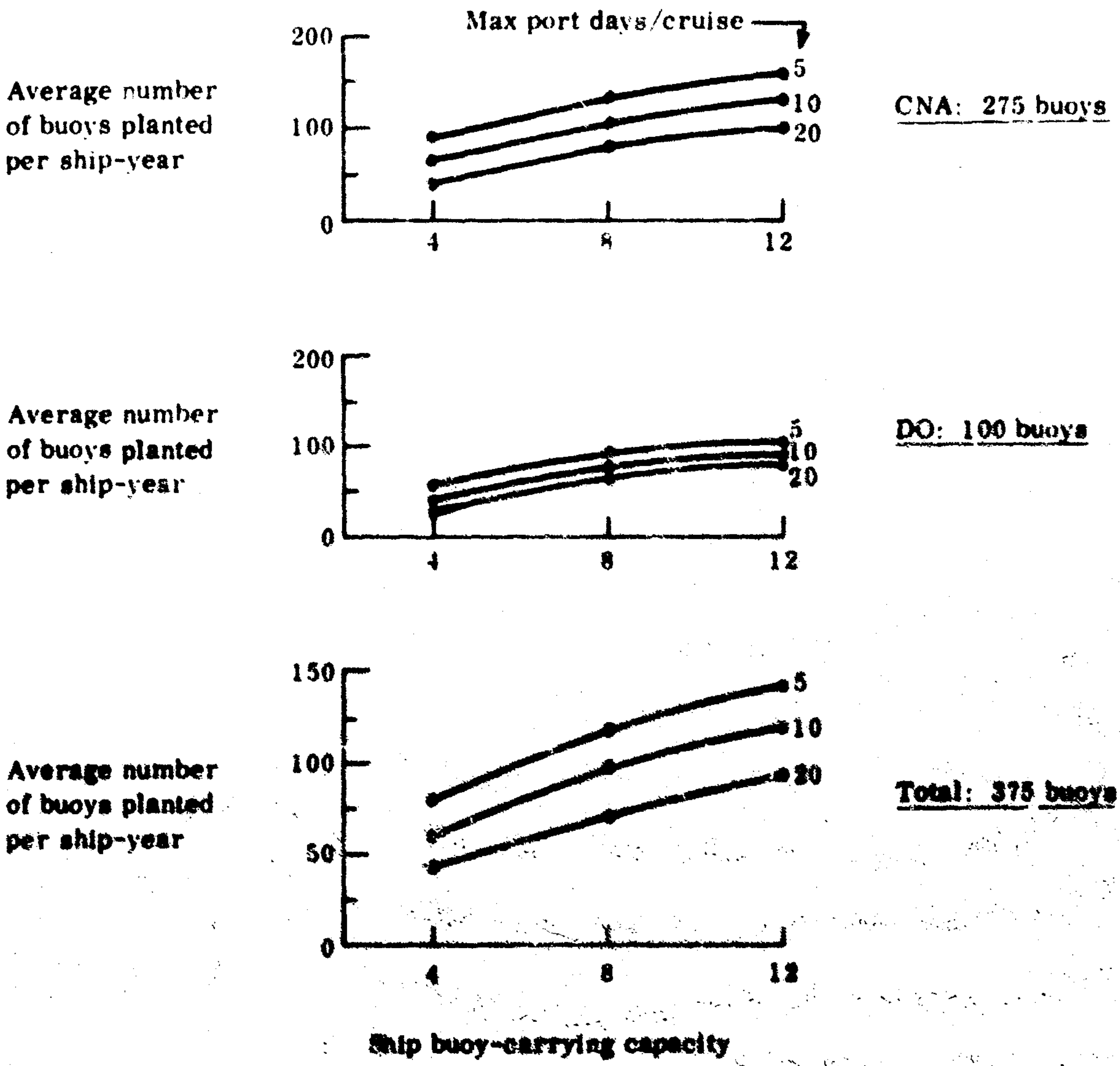


Fig. 7-16. Average Number of Buoys Planted Per Ship-Year (3-Port Deployment)

Notes: (1) Time-to-plant = 24 hr
(2) Safety factor = 1.0
(3) Ship speed = 18 kt

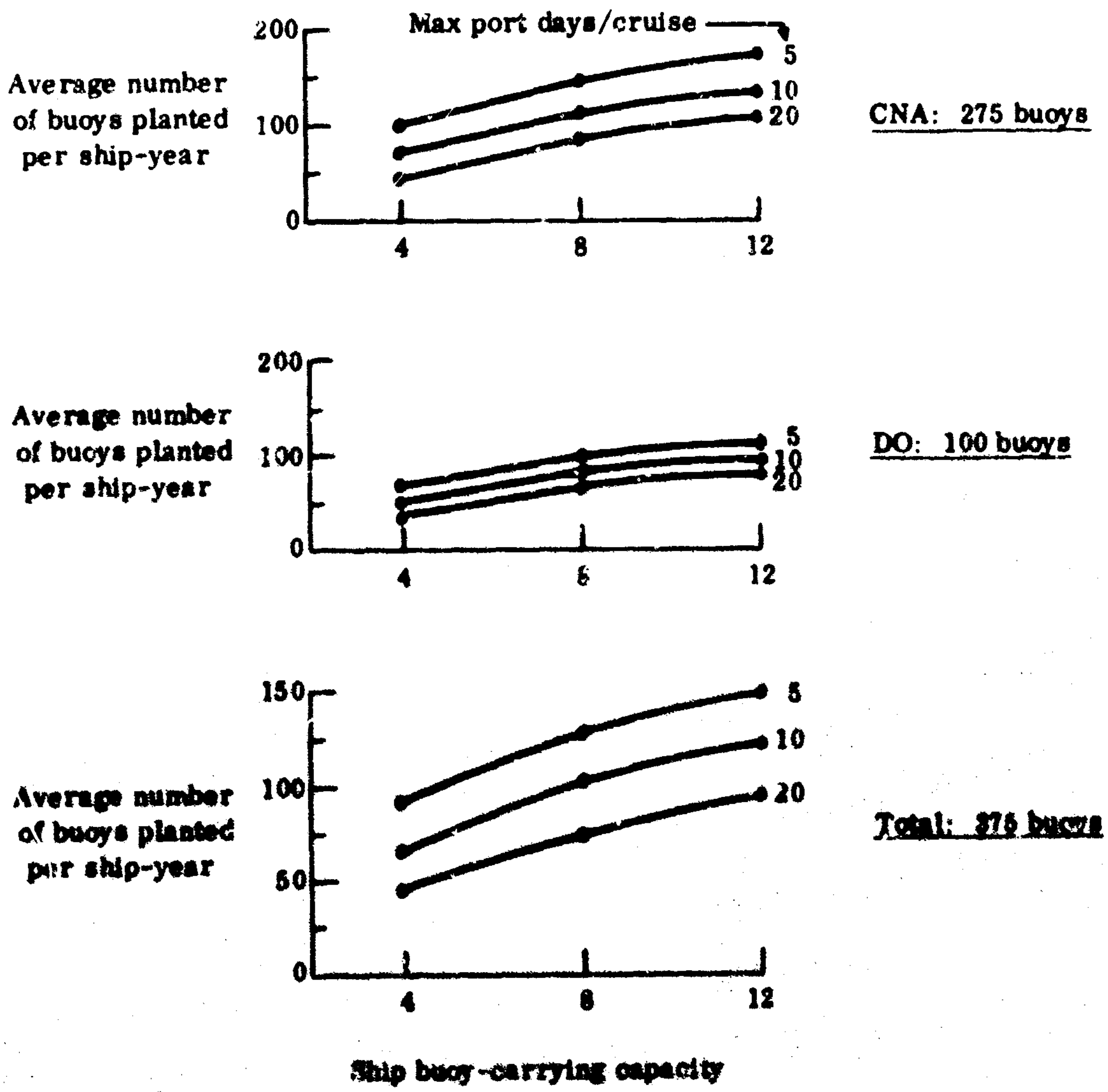


Fig. 7-17. Average Number of Buoys Planted Per Ship-Year (8-Port Deployment)

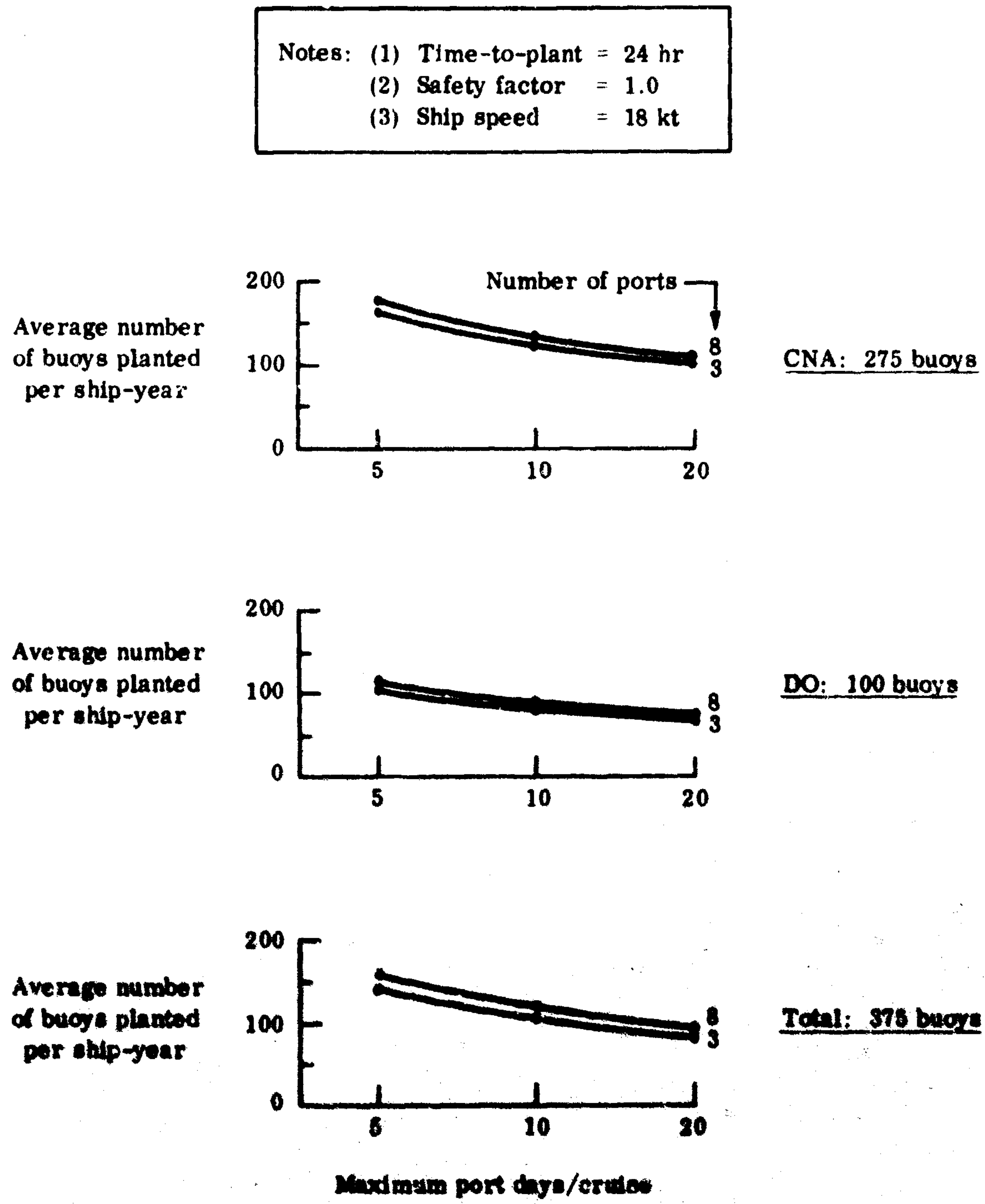


Fig. 7-18. Average Number of Buoys Planted Per Ship-Year (12-Buoy Ship)

deployment planning factors that can be modified somewhat to achieve certain desired goals.*

Table 7-2 shows that the average sensitivity of average number of buoys planted per ship-year is in the range of 1.6 to 4.7 buoys per ship-year per decreased port day. Thus, lowering the number of port days per cruise from 10 to 9 increases the average buoy-deploying capability of a 12-buoy, 18 kt ship by about 4 buoys per ship-year in the CNA region, or about 2 buoys per ship-year in the DO region.

This concludes the analysis of the effect of variation in port-days per cruise. While there is no suggestion that a definitive analysis has been performed, it is suggested that the results discussed in this section provide a reasonably firm basis for development planning efforts at this time. Simple planning factors such as the capability of a 12-buoy, 18 kt ship to deploy about 90 to 140 buoys per ship-year must be clearly qualified,† but the likely range of variation around these bounds is more of the order of 10 to 30 per cent, rather than by factors of 2 or 0.5.

The results discussed in this section have been based on a buoy "population" of 375 northern hemisphere buoys. It was shown in Section 5 that for a population of this general size, statistical results (averages) are essentially independent of minor variations in the actual number of buoys or variations in the actual locations of buoys, as long as the proportion of buoys in each of the 13 northern hemisphere MDZs is held relatively constant. These facts afford added confidence in the qualified use of these results. Rather loosely interpreted, the results given for 5 port days per cruise probably represent an upper bound on the most performance that can be expected from a deployment ship. The results for 20 port days per cruise probably represents a

---

*Note that only the feasibility of deploying 375 buoys in one year has been addressed here. The question of whether deployment of all 375 buoys by three 12-buoy, 18 kt ships within one year is an acceptable goal has not been considered. Nor has the question been addressed concerning the capability to fabricate approximately 400 data buoys in a relative short time. These questions are also important and will require thorough consideration.

†In particular, in terms of safety factor (1.0), time-to-plant (24 hrs), ship buoy-carrying capacity (12), average ship speed (18 kt), and port days per cruise (10).

lower bound on deployment performance. Thus, it is likely that this analysis has bracketed the region within which the answer lies. No more stringent interpretation of the results could be considered valid at this point in time.

8.0 RECOMMENDATIONS FOR FURTHER STUDY

The results presented in this report represent only the first step in the determination of cost-effective, preferred buoy deployment/maintenance operations. The deployment and maintenance of ocean data buoys involves a highly interrelated man-machine mix; and the operation is couched in the natural uncertainty imposed by an often hostile ocean environment. For a system of the complexity under consideration here, the advantages to be accrued by undertaking modest simulation and costing efforts are immense, for dozens of deployment/maintenance cruise schedules and parameter variations can be investigated at the cost of operating one future buoy deployment/maintenance ship for a fraction of a day.

Simulation studies are never completely finished, of course. Instead, investigation becomes more detailed in certain areas of highest interest and the model expands to cover more facets of the system and/or additional model sophistication is developed into the existing model. A good system simulation model will usually find a place in the operation of the system, once development has been completed and implementation begun. Operation of the NDBS will always be sufficiently costly to justify the use of a simulation model of modest proportion as a management guide when making additions to, or revision of, the overall system. The remainder of this section briefly outlines four of the many areas in which buoy deployment/maintenance simulation and cost studies could reduce uncertainties in the early stages of system development planning.

8.1 Deployment/Maintenance Scheduling and Ship Characteristics Optimization

It is possible at this time to begin investigating the allocation of time to the various tasks to be performed in deployment and maintenance: Investigation of bottom characteristics (for anchoring), transfer of data buoys to and from the ship, paying out and reeling in (and storing) two to three n mi of mooring for most buoys, affixing and removing clamp-on oceanographic sensor packages, testing equipment before, during, and after deployment, etc. Factors such as these impinge on man-power requirements (and, hence, base cost per sea-day) and the cruise schedule, as the ship goes from station to station. This study has made evident that buoys are not likely to be uniformly distributed throughout the world's oceans. Given this condition, it is necessary to investigate the pseudo-random effects of typical deployment patterns on conceptually

"optimum" deployment/maintenance detailed scheduling. This work could be carried out using the present TRC buoy deployment/maintenance model.

8.2 Evolutionary System Growth

This study has presented a broad view of the buoy deployment problem, with only occasional reference to the follow-on maintenance task. At this point it would be desirable to consider possible data buoy production rates and desired evolutionary system growth patterns. "Are all buoys to be deployed within a span of approximately one year, or would it be more desirable to effect deployment (and subsequent maintenance) of a system of (say, 375) buoys over a period of three years?" This question and a number of similar ones are in need of investigation at this time, because of the long leadtime required for ship construction (up to 5 years) and the need to analyze the impact of alternative system development programs. As noted elsewhere in this report, the selection of average ship speed, buoy-carrying capacity, maximum port days per cruise, and average time-to-plant establishes essentially a "quantum" system capability. This quantum capability should be correlated with the "critical mass" (i.e, density and observing capabilities) of buoys in a given area, else the deployed buoys may be unable to adequately resolve the natural phenomena in the area, and, hence, produce observations that are satisfactory for the intended data use. Thus, it would be desirable to start with the constraining ship and operational characteristics and determine approximately how well data requirements can be met by each added "quantum" of system capability. In this fashion, feasible time-phased evolutionary system growth patterns can be established and considered (elsewhere) in terms of cost-effectiveness, cost-benefits, and worth to the nation.* A study of this kind could be performed using the existing TRC buoy deployment/maintenance model.

8.3 Maintenance Optimization

Because of the cyclic nature of buoy maintenance, it is a cost recurring item and should be optimized, to the degree possible. It has been noted elsewhere in this report that buoy maintenance is looked upon as a somewhat more complex task than buoy

*System worth to the nation extends beyond the realm of purely economic benefits. Also included are social benefits, international cooperation and leadership, and enhancement of the national defense posture.

deployment, for it is presumed that both buoy and mooring retrieval and buoy and mooring deployment would take place at each required data observation site. Furthermore, if buoys are refurbished aboard ship, then number of spare buoys carried, refurbishment time, commensurate personnel requirements, etc. all become additional parameters to be considered. The operation of buoy retrieval and deployment will likely be best performed during daylight. If this becomes a requirement, then non-uniform buoy networks may add an additional dimension of complexity to "best" cruise scheduling procedures. Capability to perform the deployment/maintenance operation in six hours (or less) may become a feature of great significance.* These and similar questions can be investigated using the available TRC buoy deployment/maintenance model.

8.4 Effect of the Hostile Environment

Both statistical and (incomplete) synoptic marine environmental data records are available and should be used to determine potential adverse effects on typical buoy deployment and maintenance cruise scheduling. Synoptic environmental data records are available from the U.S. Navy Fleet Numerical Weather Center (Monterey). Also, TRC has several years of global weather records available (they are presently being used in support of an NSF/MIT global circulation study). The existing TRC buoy deployment/maintenance simulation model could be modified to determine the environmental conditions at each point of buoy deployment/maintenance. Various decisions rules (based on winds, sea state, precipitation rate, etc.) could be investigated, as a function of seasonal variations in the marine environment, for various geographical regions. Addition of this simulation feature, and use of both statistical and synoptic data would add considerable additional credence to results obtained from the TRC buoy deployment/maintenance model, as well as more thorough insight into the actual nature of future data buoy deployment/maintenance operations.

*For example, it has been pointed out in the body of this report that reducing time-to-plant from 24 to 12 hours could provide for a given ship about as much savings overall in average ship operating cost per buoy deployed as any other factor considered. Interestingly enough, reducing time-to-implant-and-retrieve to 6 hr, but requiring that implanting and retrieving take place during daylight, probably would not produce additional large savings. This point needs investigation.

9.0 REFERENCES

1. Davis, E. L., B. J. Erickson and E. R. Sweeton, 1968: Computer Programs for National Data Buoy Systems Simulation and Cost Models. TRC Report 7493-333, under Contract DOT-CG-82504-A with the U.S. Coast Guard.

2. Jenkins, E. F., E. J. Aubert, W. R. B. Caruth, L. H. Clem and R. G. Walden (AGA). 1967: A Cost Effectiveness Evaluation of Buoy and Non-Buoy Systems to Meet the National Requirements for Marine Data. TRC Report 7485-274, Final Report, Vol. 1, Part 3, under Contract TCG-16790-A with the U.S. Coast Guard.

3. Clem, L. H. and G. M. Northrop, 1968: Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meteorological and Oceanographic Data. TRC Report 7493-332, under Contract DOT-CG-82504-A with the U.S. Coast Guard.

4. Jenkins, C. F, G. M. Northrop, A. Thomasell and D. B. Spiegler, 1968: Cost Effectiveness Sensitivity of National Data Buoy Systems: An Essay. TRC Report 7493-336, under Contract DOT-CG-82504-A with the U.S. Coast Guard.

5. Northrop, G. M., W. R. B. Caruth, E. L. Davis, L. J. Reed and J. A. Russo, Jr., 1967: Cost-Benefits for a National Data Buoy System: An Essay. TRC Report 7485-280, Final Report, Vol. 2, under Contract TCG-16790-A with the U.S. Coast Guard.

APPENDIX A
TYPICAL OUTPUT FROM THE BUOY DEPLOYMENT/MAINTENANCE SIMULATION AND COST MODEL

The ten figures in this appendix provide the interested reader with an example of the computer output of the TRC buoy deployment/maintenance simulation and cost model. The data shown apply to 4 cruises with a 12-buoy ship used to deploy 48 buoys in the North Atlantic MDZ (see Fig. 5-3). The 48 buoys are part of the 500-buoy (baseline) system.

Figure A-1 gives the input buoy deployment conditions: Starting deployment date, deployment port (buoys can also be taken on at a depot after leaving port, if desired), base average cruising speed, ship buoy-carrying capacity, overall safety factor, base time to implant one buoy after arriving at location, maximum port days per cruise, etc. Also shown are the number of buoys carried on each cruise and the number of navigation points used on each cruise. For costing purposes, the base cost of the buoy (i.e., total cost, less depth dependent costs for mooring line and line-mounted oceanographic sensor packages), the unit cost of oceanographic sensor packages, and the cost per unit length of mooring must also be input. These are shown at the bottom of Fig. A-1, along with the mooring scope.

The location of all buoys, in the order deployed, is shown in Fig. A-2. This also includes computed output of the cost of each buoy, based on the ocean depth of the point deployed. The ocean depth determines the mooring length and the number of oceanographic sensor packages (using IAPSO levels and a sensor package at the bottom, if the distance to the IAPSO level above is 0.7 or more of the applicable IAPSO increment). The output provides a sum of the buoys deployed as a check.

The details of each of the four cruises are given in Fig. A-3 through Fig. A-6. (This printout can be surpressed by an input control, if desired.) Note that the deployments took (at a minimum) 43.7, 38.2, 42.2, and 36.9 days. All of these cruises (at 9 kt average ship speed) greatly exceed the 22.5 days considered desirable for a completely perfect cruise (i.e., safety factor of 1.0). The computer program makes note of the point in the cruise at which the desired cruise time was exceeded. (The desired cruise time is an input quantity and can be varied.) As can be seen, the distance back to port from each buoy is given. The program also keeps a running tally of time of events (there is a "clock" designed into the program) and total time accrued. Using one set of cost input figures, typical deployment costs are also shown.

```
RUN NBR 904   DATE  4 OCT 68

NORTH ATLANTIC MDZ      BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

STARTING DEPLOYMENT DATE =  1 JAN 69

CONSTANTS USED FOR THIS DEPLOYMENT

  PORT
    NAME  = PORTSMOUTH V
    LAT   = 36.5N
    LONG  = 76.5W

  DEPOT
    NAME  = PORTSMOUTH V
    LAT   = 36.5N
    LONG  = 76.5W

  SHIP
    NAME  =
    AVERAGE CRUISING SPEED, KTS =  9.0
    MAXIMUM BUOY CAPACITY       = 12
    OVERALL SAFETY FACTOR       =  1.33
    HOURS TO IMPLANT 1 BUOY     = 12.0
    DESIRED SEA DAYS PER CRUISE = 30.0
    MAXIMUM SEA DAYS PER CRUISE = 99.0
    MAXIMUM PRT DAYS PER CRUISE = 10.0

    LOAD/CRUISE
     12 12 12 12

    NAV POINTS/CRUISE
      1  0  0  1

  BUOY COSTS
    BUOY W/O S/S SENSORS OR MOORING = $ 158000.
    SUBSURFACE SENSOR PACKAGE, EACH = $   7000.
    MOORING LINE PER 1000 FT        = $   1750.
    MOORING SCOPE =  1.00
```

Fig. A-1. Input Buoy Deployment Conditions for North Atlantic MDZ.

RUN NBR 904   DATE 4 OCT 68

NORTH ATLANTIC MDZ   BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

BUOYS - IN ORDER DEPLOYED

NBR	DEGS LAT	DEGS LONG	DEPTH (FT)	BASIC COST	S/S PKGS	TOTAL COST
NA11	42.0N	31.5W	9600	$158000.	18	$300800.00
NA12	41.0N	20.5W	13200	$158000.	19	$314100.00
NA13	41.0N	10.0W	15000	$158000.	20	$324250.00
NA 6	49.5N	25.0W	13200	$158000.	19	$314100.00
NA 7	49.5N	12.0W	480	$158000.	8	$214840.00
NA 8	50.2N	0.4W	100	$158000.	4	$186175.00
NA 4	59.0N	2.0E	500	$158000.	8	$214875.00
NA 2	58.5N	17.5W	4800	$158000.	16	$278400.00
NA 1	58.0N	34.0W	7200	$158000.	17	$289600.00
NA 5	49.5N	38.0W	12000	$158000.	19	$312000.00
NA10	43.5N	41.5W	15000	$158000.	20	$324250.00
NA 9	38.0N	55.0W	16200	$158000.	20	$326350.00
NA22	24.5N	54.5W	18000	$158000.	20	$329500.00
NA23	24.5N	46.0W	12000	$158000.	19	$312000.00
NA24	25.0N	37.0W	15000	$158000.	20	$324250.00
NA25	25.0N	28.0W	18000	$158000.	20	$329500.00
NA26	24.5N	19.0W	10800	$158000.	18	$302900.00
NA20	33.0N	10.5W	14000	$158000.	19	$315500.00
NA14	36.0N	5.8W	300	$158000.	7	$207525.00
NA19	33.0N	20.0W	15000	$158000.	20	$324250.00
NA18	31.5N	29.5W	12000	$158000.	19	$312000.00
NA17	33.0N	38.0W	9600	$158000.	18	$300800.00
NA16	35.0N	48.5W	12000	$158000.	19	$312000.00
NA15	33.0N	58.5W	15600	$158000.	20	$325300.00
NA39	8.2N	43.0W	15000	$158000.	20	$324250.00
NA44	0.5N	41.5W	15000	$158000.	20	$324250.00
NA45	0.2N	33.0W	15000	$158000.	20	$324250.00
NA40	3.2N	34.5W	15600	$158000.	20	$325300.00
NA41	8.2N	26.5W	15000	$158000.	20	$324250.00
NA46	0.2N	25.5W	12000	$158000.	19	$312000.00
NA47	0.2N	18.0W	12000	$158000.	19	$312000.00
NA42	8.2N	18.2W	15000	$158000.	20	$324250.00
NA36	16.8N	18.2W	9000	$158000.	18	$299750.00
NA35	16.5N	27.0W	15000	$158000.	20	$324250.00
NA34	16.5N	35.0W	16200	$158000.	20	$326350.00
NA33	16.5N	43.0W	15000	$158000.	20	$324250.00
NA27	17.0N	81.7W	1533	$158000.	12	$244683.00
NA28	16.0N	73.5W	9000	$158000.	18	$299750.00
NA 3	13.0N	78.5W	12000	$158000.	19	$312000.00
NA29	17.0N	67.0W	11400	$158000.	19	$310950.00
NA30	15.5N	64.5W	6000	$158000.	17	$287500.00
NA31	14.8N	59.0W	18000	$158000.	20	$329500.00
NA37	10.0N	60.0W	600	$158000.	9	$222050.00
NA43	2.0N	48.0W	400	$158000.	8	$214700.00
NA38	8.2N	51.5W	15010	$158000.	20	$324268.00
NA32	16.5N	51.5W	15000	$158000.	20	$324250.00
NA48	22.8N	61.6W	18900	$158000.	20	$331075.00
NA21	25.5N	66.0W	18000	$158000.	20	$329500.00

TOTAL BUOY HARDWARE COST (W/O SPARES) $ 14470639.00

TOTAL NBR OF BUOYS TO BE DEPLOYED = 48

Fig. A-2. Buoy Locations, Depths, Number of Oceanographic Sensor Packages Required, and Buoy Hardware Costs.

RUN NBR 904   DATE 4 OCT 68

NORTH ATLANTIC MDZ   BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

CRUISE DEPLOYMENT SUMMARY

CRUISE 1

ON-LOADED 12 BUOYS AT PORTSMOUTH V
SHIP UNDERWAY 1 JAN 69 AT 800 HRS, SEADAYS = 0.0

BUOYS IMPLANTED IN FOLLOWING ORDER

BUOY NBR	DEGS LAT	DEGS LONG	N MI BTWN	N MI TO PORT	DATE	SEA DAY	DPLYMT DAY
NA11	42.0N	31.5W	2096	2096	11 JAN	10.2	10.2
NA12	41.0N	20.5W	498	2594	14 JAN	13.0	13.0
NA13	41.0N	10.0W	476	3053	17 JAN	15.7	15.7
NA 6	49.5N	25.0W	812	2343	21 JAN	20.0	20.0

EXCEEDED DESIRED SEA DAYS TO IMPLANT ABOVE BUOY

NA 7	49.5N	12.0W	506	2848	24 JAN	22.8	22.8
NA 8	50.2N	0.4W	451	3276	26 JAN	25.4	25.4
NV50	51.0N	1.0E	71	3313	27 JAN	25.7	25.7
NA 4	59.0N	2.0E	482	3276	29 JAN	28.5	28.5
NA 2	58.5N	17.5W	606	2624	3 FEB	31.8	31.8
NA 1	58.0N	34.0W	521	2107	6 FEB	34.7	34.7
NA 5	49.5N	38.0W	530	1838	8 FEB	37.7	37.7
NA10	43.5N	41.5W	388	1652	11 FEB	40.0	40.0
NA 9	38.0N	55.0W	696	1030	14 FEB	43.7	43.7

SHIP RETURNED TO PORTSMOUTH V ON 19 FEB 69 AT 1700 HRS

N MILES STEAMED THIS CRUISE = 9168

BUOYS IMPLANTED THIS CRUISE = 12

TOTAL BUOY IMPLANTED TO DATE = 12
BUOYS REMAINING TO BE DPLYD = 36

MINIMUM PSBL SEA DAYS FOR THIS CRUISE = 48.4
MINIMUM REQUIRED PORT DAYS   = 10.0

MINIMUM PSBL DEPLOYMENT DAYS TO DATE = 58.4

MIN DPLYMT DAYS X SAFETY FACTOR   = 77.7

----------- AT $ 5600.00 PER SEA DAY -----------
MINIMUM SHIP COST FOR THIS CRUISE $ 376949.00
MIN SHIP COST X SAFETY FACTOR $ 501342.00

TOTAL MINIMUM SHIP COST TO DATE $ 376949.00

TOTAL MIN COST X SAFETY FACTOR $ 501342.00

Fig. A-3. Detailed Output for First North Atlantic MDZ Deployment Cruise.

RUN NBR 904   DATE 4 OCT 68

NORTH ATLANTIC MDZ   BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

CRUISE DEPLOYMENT SUMMARY

CRUISE 2

ON-LOADED 12 BUOYS AT PORTSMOUTH V
SHIP UNDERWAY 29 FEB 69 AT 1700 HRS, SEADAYS = 0.0

BUOYS IMPLANTED IN FOLLOWING ORDER

BUOY NBR	DEGS LAT	DEGS LONG	N MI BTWN	N MI TO PORT	DATE	SEA DAY	DPLYMT DAY
NA22	24.5N	54.5W	1343	1343	6 MAR	6.7	65.2
NA23	24.5N	46.0W	464	1726	9 MAR	9.4	67.8
NA24	25.0N	37.0W	492	2137	11 MAR	12.1	70.6
NA25	25.0N	28.0W	490	2570	14 MAR	14.9	73.4
NA26	24.5N	19.0W	492	3019	17 MAR	17.7	76.1

EXCEEDED DESIRED SEA DAYS TO IMPLANT ABOVE BUOY

NA20	33.0N	10.5W	678	3201	21 MAR	21.3	79.8
NA14	36.0N	5.8W	294	3343	22 MAR	23.2	81.7
NA19	33.0N	20.0W	725	2758	26 MAR	27.1	85.5
NA18	31.5N	29.5W	491	2338	29 MAR	29.8	88.3
NA17	33.0N	38.0W	441	1900	2 APR	32.4	90.8
NA16	35.0N	48.5W	536	1364	5 APR	35.4	93.8
NA15	33.0N	58.5W	512	912	8 APR	38.2	96.7

SHIP RETURNED TO PORTSMOUTH V ON 12 APR 69 AT 500 HRS

N MILES STEAMED THIS CRUISE = 7874

BUOYS IMPLANTED THIS CRUISE = 12

TOTAL BUOY IMPLANTED TO DATE = 24
BUOYS REMAINING TO BE DPLYD = 24

MINIMUM PSBL SEA DAYS FOR THIS CRUISE = 42.5
MINIMUM REQUIRED PORT DAYS = 10.0

MINIMUM PSBL DEPLOYMENT DAYS TO DATE = 110.9

MIN DPLYMT DAYS X SAFETY FACTOR = 147.5

------------ AT $ 5600.00 PER SEA DAY ------------
MINIMUM SHIP COST FOR THIS CRUISE $ 335923.00
MIN SHIP COST X SAFETY FACTOR $ 446777.00

TOTAL MINIMUM SHIP COST TO DATE $ 712872.00

TOTAL MIN COST X SAFETY FACTOR $ 948120.00

Fig. A-4. Detailed Output for Second North Atlantic MDZ Deployment Cruise.

RUN NBR 904   DATE 4 OCT 68

NORTH ATLANTIC MDZ   BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

CRUISE DEPLOYMENT SUMMARY

CRUISE 3

ON-LOADED 12 BUOYS AT PORTSMOUTH V
SHIP UNDERWAY 27 APR 69 AT 500 HRS, SEADAYS = 0.0

BUOYS IMPLANTED IN FOLLOWING ORDER

BUOY NBR	DEGS LAT	DEGS LONG	N MI BTWN	N MI TO PORT	DATE	SEA DAY	DPLYMT DAY
NA39	8.2N	43.0W	2497	2497	4 MAY	12.1	123.0
NA44	0.5N	41.5W	471	2910	6 MAY	14.7	125.7
NA45	0.2N	33.0W	511	3257	9 MAY	17.6	128.5
EXCEEDED DESIRED SEA DAYS TO IMPLANT ABOVE BUOY							
NA40	8.2N	34.5W	489	2852	12 MAY	20.4	131.3
NA41	8.2N	26.5W	475	3209	15 MAY	23.1	134.0
NA46	0.2N	25.5W	484	3574	18 MAY	25.8	136.7
NA47	0.1N	18.0W	450	3913	20 MAY	28.4	139.3
NA42	8.2N	18.2W	487	3594	23 MAY	31.2	142.1
NA36	16.8N	18.2W	516	3294	26 MAY	34.1	145.0
NA35	16.5N	27.0W	507	2883	29 MAY	36.9	147.8
NA34	16.5N	35.0W	461	2508	1 JUN	39.5	150.5
NA33	16.5N	43.0W	461	2148	4 JUN	42.2	153.1

SHIP RETURNED TO PORTSMOUTH V ON 14 JUN 69 AT 700 HRS

N MILES STEAMED THIS CRUISE = 9962

BUOYS IMPLANTED THIS CRUISE = 12

TOTAL BUOY IMPLANTED TO DATE = 36
BUOYS REMAINING TO BE DPLYD = 12

MINIMUM PSBL SEA DAYS FOR THIS CRUISE = 52.1
MINIMUM REQUIRED PORT DAYS = 10.0

MINIMUM PSBL DEPLOYMENT DAYS TO DATE = 173.0

MIN DPLYMT DAYS X SAFETY FACTOR = 230.1

------------ AT $ 5600.00 PER SEA DAY ------------
MINIMUM SHIP COST FOR THIS CRUISE $ 402121.00
MIN SHIP COST X SAFETY FACTOR $ 534821.00

TOTAL MINIMUM SHIP COST TO DATE $ 1114992.00

TOTAL MIN COST X SAFETY FACTOR $ 1482939.00

Fig. A-5. Detailed Output for Third North Atlantic MDZ Deployment Cruise.

RUN NBR 904   DATE 4 OCT 68

NORTH ATLANTIC MDZ   BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

CRUISE DEPLOYMENT SUMMARY

CRUISE 4

ON-LOADED 12 BUOYS AT PORTSMOUTH V
SHIP UNDERWAY 24 JUN 69 AT 700 HRS, SEADAYS = 0.0

BUOYS IMPLANTED IN FOLLOWING ORDER

BUOY NBR	DEGS LAT	DEGS LONG	N MI BTWN	N MI TO PORT	DATE	SEA DAY	DPLYMT DAY
NV49	20.0N	74.0W	1000	1000	28 JUN	4.6	177.7
NA27	17.0N	81.7W	474	1204	1 JUL	7.3	180.4
NA28	16.0N	73.5W	476	1242	4 JUL	10.0	183.1
NA 3	13.0N	78.5W	342	1416	6 JUL	12.1	185.1
NA29	17.0N	67.0W	709	1276	10 JUL	15.9	188.9
NA30	15.5N	64.5W	170	1416	11 JUL	17.2	190.2
NA31	16.8N	59.0W	327	1506	13 JUL	19.2	192.2
NA37	10.0N	60.0W	412	1828	15 JUL	21.6	194.6
EXCEEDED DESIRED SEA DAYS TO IMPLANT ABOVE BUOY							
NA43	2.0N	48.0W	863	2607	20 JUL	26.1	199.1
NA38	8.2N	51.5W	427	2181	22 JUL	28.6	201.6
NA32	16.5N	51.5W	498	1793	25 JUL	31.4	204.4
NA48	22.8N	61.6W	685	1130	29 JUL	35.1	208.1
NA21	25.5N	66.0W	290	853	1 AUG	36.9	210.0

SHIP RETURNED TO PORTSMOUTH V ON 5 AUG 69 AT 400 HRS

N MILES STEAMED THIS CRUISE = 7531

BUOYS IMPLANTED THIS CRUISE = 12

TOTAL BUOY IMPLANTED TO DATE = 48
BUOYS REMAINING TO BE DPLYD = 0

MINIMUM PSBL SEA DAYS FOR THIS CRUISE = 40.9
MINIMUM REQUIRED PORT DAYS = 10.0

MINIMUM PSBL DEPLOYMENT DAYS TO DATE = 223.9

MIN DPLYMT DAYS X SAFETY FACTOR = 297.8

------------ AT $ 5600.00 PER SEA DAY ------------
MINIMUM SHIP COST FOR THIS CRUISE $ 325046.00
MIN SHIP COST X SAFETY FACTOR $ 432311.00

TOTAL MINIMUM SHIP COST TO DATE $ 1440037.00

TOTAL MIN COST X SAFETY FACTOR $ 1915249.00

Fig. A-6. Detailed Output for Fourth North Atlantic MDZ Deployment Cruise.

The crucial output values from all cruises are combined in Fig. A-7, the system deployment summary. At this point are listed the total distance traveled to deploy all buoys, the total length of mooring line required and the average depth, the total and average number of oceanographic sensor packages, total and average hardware costs, and many other key items.

For the system operation simulated by the buoy deployment/maintenance model, distance traveled depends only on location of ports, buoys, and navigation points. Buoy costs depend on assigned input values and depth. But the ship operating cost is a function of distance traveled, speed, port days per cruise, time-to-plant each buoy, and ship base cost per sea-day, fuel cost, and ship maintenance cost. Thus, once the total distance traveled has been computed, variables in several other dimensions must be considered. Figure A-8 through Fig. A-10 show the data needed to make an analysis of the complex interactions of the variables. The base conditions are listed at the top of each figure, including a matrix of costs for the various conditions to be investigated. The remainder of each of these three output sheets shows various parameter output values for variations in time-to-plant and ship speed. In the three "Deployment Cost" columns, minima can be identified at speeds of 15 or 18 kt in all three figures. Minima in deployment costs occurred at speeds of 15 or 18 kt for all deployment configurations and cost inputs used in this study. As shown elsewhere in this report, addition of prorated ship construction cost does not alter this important result.

In Fig. A-8 through Fig. A-10, certain output data are presented on the basis of a safety factor of 1.0 and a safety factor of 4/3. A safety factor of 1.0 implies minimum time and cost for the stipulated conditions. Results based on safety factor of 1.0 are, therefore, lower bound results (for the stipulated input data).* Use of a safety factor of 4/3 gives numerical results for comparative purposes that represent highly probable upper bounds on these values. In other words, cruises will probably not take longer and costs will probably not be greater than 133% of the minimum attainable values for the given input conditions.

---

*That is, cruises will take at least as long and deployment will cost at least as much as the results found using a safety factor of 1.0.

RUN NBR 904   DATE 4 OCT 68

NORTH ATLANTIC MDZ   BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

SYSTEM DEPLOYMENT SUMMARY

STARTING DATE = 1 JAN 69 AT 800 HRS

CRUISE NBR	BUOYS DPLYD	N MILES STEAMED	MIN SHIP SEA DAYS	MIN SHIP PRT DAYS	TOTAL MIN DPLY DAYS	MIN X SAFETY
1	12	9168	48.4	10.0	58.4	77.7
2	12	7874	42.5	10.0	52.5	69.8
3	12	9962	52.1	10.0	62.1	82.6
4	12	7531	40.9	10.0	50.9	67.7
4	48	34538	183.9	40.0	223.9	297.8

------------- AT $ 5600.00 PER SEA DAY -------------

MINIMUM SHIP COST FOR THIS DEPLOYMENT $ 1440037.00
MINIMUM SHIP COST X SAFETY FACTOR $ 1915249.00

TOTAL COST FOR BUOY HARDWARE DEPLOYED $ 14470639.00

TOTAL FEET OF MOORING REQUIRED = 555223
TOTAL S/S SENSOR PACKAGES DPLYD =   845

AVERAGE DEPTH PER BUOY IN MDZ   = 11567
AVERAGE NBR OF S/S PKGS PER BUOY IN MDZ =   17

AVERAGE HARDWARE COST PER BUOY IN MDZ $ 301472.00

AVERAGE DISTANCE TRAVELED PER BUOY DEPLOYED =   719 N MI

SUMMARY OF CONSTANTS USED FOR THIS DEPLOYMENT
  SHIP AVERAGE SPEED   = 9.0
  SHIP MAX BUOY CAPACITY = 12
  HRS TO IMPLANT 1 BUOY = 12.0

MAXIMUM GEOGRAPHICAL LOCATIONS

WEST		NORTH		EAST		SOUTH	
17.0N	81.7W	59.0N	2.0E	59.0N	2.0E	0.1N	18.0W

THE SHORTEST MOORING WAS   100 FEET AT 50.2N   0.4W
THE DEEPEST MOORING WAS 18900 FEET AT 22.8N 61.6W

Fig. A-7. System Deployment Summary: Output for All Four North Atlantic MDZ Deployment Cruises.

RUN NBR 934 DATE 4 OCT 68

DEPLOYMENT TEST SUMMARY

NORTH ATLANTIC MOZ BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

48 BUOYS DEPLOYED FROM PORTSMOUTH V SHIP BUOY CAPACITY = 12
TOTAL DISTANCE, N MI = 34538 MAXIMUM CRUISE, N MI = 9962
BASE COST PER SEA DAY = $ 2000.00 COST/PORT DAY =0.94 X SEA DAY

SPEED KN	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00
CST/MI $	5.78	5.78	5.78	7.01	11.27	16.43	23.37	30.00
ADD/DY $	600.00	600.00	600.00	600.00	780.00	980.00	1200.00	1400.00

AVG SHIP SPD	MAX CRSE (DAYS)	MIN SEA DAYS	MIN PORT DAYS	MIN DPLY DAYS	MIN K SAF FCTR	DEPLOYMENT COST, $K MIN DPLY DAYS	K SAF FACTOR	AVG/BUOY (MIN)	AVG MIN DPLY DAYS PER BUOY	AVG NBR BUOYS DPLY PER SHIP IN 335 DAYS
12 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 24.0 DAYS -----										
9.0	52.1	183.9	40.0	223.9	297.8	775.5	1031.5	16.2	4.7	72
12.0	40.6	143.9	40.0	183.9	244.6	671.6	893.2	14.0	3.8	87
15.0	33.7	119.9	40.0	159.9	212.7	609.2	810.3	12.7	3.3	101
18.0	29.1	104.0	40.0	144.0	191.5	610.1	811.5	12.7	3.0	112
21.0	25.8	92.5	40.0	132.5	176.3	751.0	998.8	15.6	2.8	121
24.0	23.3	84.0	40.0	124.0	164.9	929.7	1236.5	19.4	2.6	130
27.0	21.4	77.3	40.0	117.3	156.0	1174.8	1562.5	24.5	2.4	137
30.0	19.8	72.0	40.0	112.0	149.9	1408.7	1873.6	29.3	2.3	144
24 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 48.0 DAYS -----										
9.0	59.1	207.9	40.0	247.9	329.7	837.9	1114.5	17.5	5.2	65
12.0	46.6	167.9	40.0	207.9	276.5	734.0	976.2	15.3	4.3	77
15.0	39.7	143.9	40.0	183.9	244.6	671.6	893.3	14.0	3.8	87
18.0	35.1	128.0	40.0	168.0	223.4	672.5	894.5	14.0	3.5	96
21.0	31.8	116.5	40.0	156.5	208.2	817.7	1087.6	17.0	3.3	103
24.0	29.3	108.0	40.0	148.0	196.8	1001.2	1331.7	20.9	3.1	109
27.0	27.4	101.3	40.0	141.3	187.9	1251.6	1664.7	26.1	2.9	114
30.0	25.8	96.0	40.0	136.0	180.8	1490.3	1982.1	31.0	2.8	118
30 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 60.0 DAYS -----										
9.0	61.1	219.9	40.0	259.9	345.7	869.1	1156.0	18.1	5.4	62
12.0	49.6	179.9	40.0	219.9	292.5	765.2	1017.7	15.9	4.6	73
15.0	42.7	155.9	40.0	195.9	260.6	702.8	934.8	14.6	4.1	82
18.0	38.1	140.0	40.0	180.0	239.3	703.7	936.0	14.7	3.7	89
21.0	34.8	128.5	40.0	168.5	224.1	851.1	1131.9	17.7	3.5	95
24.0	32.3	120.0	40.0	160.0	212.8	1037.0	1379.2	21.6	3.3	101
27.0	30.4	113.3	40.0	153.3	203.9	1290.0	1715.8	26.9	3.2	105
30.0	29.8	108.0	40.0	148.0	196.8	1531.1	2036.4	31.9	3.1	109
36 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 72.0 DAYS -----										
9.0	64.1	231.9	40.0	271.9	361.6	900.3	1197.4	18.8	5.7	59
12.0	52.6	191.9	40.0	231.9	308.5	796.4	1059.2	16.6	4.8	69
15.0	45.7	167.9	40.0	207.9	276.6	734.0	976.3	15.3	4.3	77
18.0	41.1	152.0	40.0	192.0	255.3	734.9	977.5	15.3	4.0	84
21.0	37.8	140.5	40.0	180.5	240.1	884.4	1176.3	18.4	3.8	89
24.0	35.3	132.0	40.0	172.0	228.7	1072.8	1426.8	22.3	3.6	94
27.0	33.4	125.3	40.0	165.3	219.8	1328.4	1766.8	27.7	3.4	97
30.0	31.8	120.0	40.0	160.0	212.8	1571.9	2090.6	32.7	3.3	101

Fig. A-8. Deployment Test Summary: $2000 Base Cost Per Sea Day.

RUN NBR 924 DATE 4 OCT 68

DEPLOYMENT TEST SUMMARY

NORTH ATLANTIC MDZ BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

48 BUOYS DEPLOYED FROM PORTSMOUTH V SHIP BUOY CAPACITY = 12
TOTAL DISTANCE, N MI = 34538 MAXIMUM CRUISE, N MI = 9962
BASE COST PER SEA DAY = $ 5000.00 COST/PORT DAY =0.94 X SEA DAY

SPEED KN	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00
CST/MI $	5.78	5.78	5.78	7.01	11.27	16.43	23.37	30.00
ADD/DY $	500.00	600.00	600.00	600.00	780.00	980.00	1200.00	1400.00

AVG SHIP SPD	MAX CRSE (DAYS)	MIN SEA DAYS	MIN PORT DAYS	MIN DPLY DAYS	MIN X SAF FCTR	DEPLOYMENT COST, $K MIN DPLY DAYS	X SAF FACTOR	AVG/BUOY (MIN)	AVG MIN DPLY DAYS PER BUOY	AVG NBR BUOYS DPLY PER SHIP IN 335 DAYS
12 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 24.0 DAYS -----										
9.0	52.1	183.9	40.0	223.9	297.8	1440.0	1915.3	30.0	4.7	72
12.0	40.6	143.9	40.0	183.9	244.6	1216.2	1617.5	25.3	3.8	87
15.0	33.7	119.9	40.0	159.9	212.7	1081.9	1438.9	22.5	3.3	101
18.0	29.1	104.0	40.0	144.0	191.5	1034.8	1376.3	21.6	3.0	112
21.0	25.8	92.5	40.0	132.5	176.3	1141.4	1518.1	23.8	2.8	121
24.0	23.3	84.0	40.0	124.0	164.9	1294.4	1721.6	27.0	2.6	130
27.0	21.4	77.3	40.0	117.3	156.0	1519.5	2021.0	31.7	2.4	137
30.0	19.8	72.0	40.0	112.0	148.9	1737.4	2310.8	36.2	2.3	144
24 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 48.0 DAYS -----										
9.0	58.1	207.9	40.0	247.9	329.7	1574.4	2094.0	32.8	5.2	65
12.0	46.6	167.9	40.0	207.9	276.5	1350.6	1796.3	28.1	4.3	77
15.0	39.7	143.9	40.0	183.9	244.6	1216.3	1617.6	25.3	3.8	87
18.0	35.1	128.0	40.0	168.0	223.4	1169.2	1555.0	24.4	3.5	96
21.0	31.8	116.5	40.0	156.5	208.2	1280.1	1702.6	26.7	3.3	103
24.0	29.3	108.0	40.0	148.0	196.9	1437.9	1912.5	30.0	3.1	109
27.0	27.4	101.3	40.0	141.3	187.9	1668.3	2218.9	34.8	2.9	114
30.0	25.8	96.0	40.0	136.0	180.8	1891.0	2515.0	39.4	2.8	118
30 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 60.0 DAYS -----										
9.0	61.1	219.9	40.0	259.9	345.7	1641.6	2183.4	34.2	5.4	62
12.0	49.6	179.9	40.0	219.9	292.5	1417.8	1885.6	29.5	4.6	73
15.0	42.7	155.9	40.0	195.9	260.6	1283.5	1707.0	26.7	4.1	82
18.0	38.1	140.0	40.0	180.0	239.3	1236.4	1644.4	25.8	3.7	89
21.0	34.8	128.5	40.0	168.5	224.1	1349.5	1794.8	28.1	3.5	95
24.0	32.3	120.0	40.0	160.0	212.8	1509.7	2007.9	31.5	3.3	101
27.0	30.4	113.3	40.0	153.3	203.9	1742.7	2317.9	36.3	3.2	105
30.0	28.8	108.0	40.0	148.0	196.8	1967.8	2617.2	41.0	3.1	109
36 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 72.0 DAYS -----										
9.0	64.1	231.9	40.0	271.9	361.6	1708.8	2272.8	35.6	5.7	59
12.0	52.6	191.9	40.0	231.9	308.9	1485.0	1975.0	30.9	4.8	69
15.0	45.7	167.9	40.0	207.9	276.6	1350.7	1796.4	28.1	4.3	77
18.0	41.1	152.0	40.0	192.0	255.3	1303.6	1733.8	27.2	4.0	84
21.0	37.8	140.5	40.0	180.5	240.1	1418.8	1887.1	29.6	3.8	89
24.0	35.3	132.0	40.0	172.0	228.7	1581.5	2103.3	32.9	3.6	94
27.0	33.4	125.3	40.0	165.3	219.8	1817.1	2416.8	37.9	3.4	97
30.0	31.8	120.0	40.0	160.0	212.8	2044.6	2719.3	42.6	3.3	101

Fig. A-9. Deployment Test Summary: $5000 Base Cost Per Sea Day.

RUN NO. 934 DATE 4 OCT 68

DEPLOYMENT TEST SUMMARY

NORTH ATLANTIC M07 BASE LINE (500) BUOY LOCATIONS
INCLUDES NEW SHIP SEA-DAY AND PORT-DAY COST COMPUTATIONS

48 BUOYS DEPLOYED FROM PORTSMOUTH V SHIP BUOY CAPACITY = 12
TOTAL DISTANCE, N MI = 34539 MAXIMUM CRUISE, N MI = 9962
BASE COST PER SEA DAY = $ 8000.00 COST/PORT DAY =0.94 X SEA DAY

SPEED KN	9.00	12.00	15.00	18.00	21.00	24.00	27.00	30.00
CST/MI $	5.78	5.78	5.78	7.01	11.27	16.43	23.37	30.00
ADD/DY $	600.00	600.00	600.00	600.00	780.00	980.00	1200.00	1400.00

AVG SHIP SPD	MAX CRSE (DAYS)	MIN SEA DAYS	MIN PORT DAYS	MIN DPLY DAYS	MIN X SAF FCTR	DEPLOYMENT COST, $K MIN DPLY DAYS	X SAF FACTOR	AVG/BUOY (MIN)	AVG MIN DPLY DAYS PER BUOY	AVG NBR BUOYS DPLY PER SHIP IN 335 DAYS
12 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 24.0 DAYS -----										
9.0	52.1	183.9	40.0	223.9	297.8	2104.5	2799.0	43.8	4.7	72
12.0	40.6	143.9	40.0	183.9	244.6	1760.8	2341.8	36.7	3.8	87
15.0	33.7	119.9	40.0	159.9	212.7	1554.5	2067.5	32.4	3.3	101
18.0	27.1	104.0	40.0	144.0	191.5	1459.4	1941.1	30.4	3.0	112
21.0	25.8	92.5	40.0	132.5	176.3	1531.8	2037.3	31.9	2.8	121
24.0	23.3	84.0	40.0	124.0	164.9	1659.1	2206.6	34.6	2.6	130
27.0	21.4	77.3	40.0	117.3	156.0	1864.2	2479.5	38.8	2.4	137
30.0	19.8	72.0	40.0	112.0	148.9	2066.1	2747.9	43.0	2.3	144
24 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 48.0 DAYS -----										
9.0	59.1	207.9	40.0	247.9	329.7	2310.9	3073.6	48.1	5.2	65
12.0	46.6	167.9	40.0	207.9	276.5	1967.2	2616.3	41.0	4.3	77
15.0	39.7	143.9	40.0	183.9	244.6	1760.9	2342.0	36.7	3.8	87
18.0	35.1	128.0	40.0	168.0	223.4	1665.9	2215.6	34.7	3.5	96
21.0	31.8	116.5	40.0	156.5	208.2	1742.5	2317.5	36.3	3.3	103
24.0	29.3	108.0	40.0	148.0	196.8	1874.6	2493.2	39.1	3.1	109
27.0	27.4	101.3	40.0	141.3	187.9	2085.0	2773.1	43.4	2.9	114
30.0	25.8	96.0	40.0	136.0	180.9	2291.7	3048.0	47.7	2.8	118
30 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 60.0 DAYS -----										
9.0	61.1	219.9	40.0	259.9	345.7	2414.1	3210.8	50.3	5.4	62
12.0	49.6	179.9	40.0	219.9	292.5	2070.4	2753.6	43.1	4.6	73
15.0	42.7	155.9	40.0	195.9	260.6	1864.1	2479.2	38.8	4.1	82
18.0	39.1	150.0	40.0	190.0	253.3	1769.0	2352.8	36.9	3.7	89
21.0	34.8	128.5	40.0	168.5	224.1	1847.9	2457.7	38.5	3.5	95
24.0	32.3	120.0	40.0	160.0	212.8	1982.4	2636.6	41.3	3.3	101
27.0	30.4	113.3	40.0	153.3	203.9	2195.4	2919.9	45.7	3.2	105
30.0	28.9	108.0	40.0	148.0	196.8	2404.5	3198.0	50.1	3.1	109
36 HRS TO IMPLANT A BUOY, TOTAL TIME TO IMPLANT = 72.0 DAYS -----										
9.0	64.1	231.9	40.0	271.9	361.6	2517.3	3348.1	52.4	5.7	59
12.0	52.6	191.9	40.0	231.9	308.5	2173.6	2890.8	45.3	4.8	69
15.0	45.7	167.9	40.0	207.9	276.6	1967.3	2616.5	41.0	4.3	77
18.0	41.1	152.0	40.0	192.0	255.3	1872.2	2490.1	39.0	4.0	84
21.0	37.8	140.5	40.0	180.5	240.1	1953.2	2597.8	40.7	3.8	89
24.0	35.3	132.0	40.0	172.0	228.7	2090.1	2779.9	43.5	3.6	94
27.0	33.4	125.3	40.0	165.3	219.8	2305.8	3066.8	48.0	3.4	97
30.0	31.8	120.0	40.0	160.0	212.8	2517.3	3348.0	52.4	3.3	101

Fig. A-10. Deployment Test Summary · $8000 Base Cost Per Sea Day.

APPENDIX B

STRATEGIES FOR BUOY DEPLOYMENT CRUISE SCHEDULES

In the course of developing the TRC buoy deployment/maintenance simulation and cost computer model, it was recognized that manual choice would have to be made for locations of buoy, ports, and navigation points. It was also elected to use manual selection for buoy deployment cruise scheduling.*

While it was intuitively apparent that certain cruise schedules would be "better" than others, it was also agreed that a limited amount of analysis was needed to delineate between or among strategies for cruise scheduling that appeared essentially equally good. The analysis was performed on a series of models that might best be described as first approximations to typical data buoy networks of the future. By constraining the geometry of the deployment configuration to easily handled cases, it has been possible to show preference of deployment schemes, even to the point of establishing a crossover point of preference between two alternative schemes.

The results obtained corroborate "common sense" strategies, and give guidance where the difference in the metric (total distance traveled) of two schemes is small. This analysis was used as a guide for the deployment schedules used in the study presented in this report.

B.1 Approach

Deployment of data buoys from a port to a close-by or distant region is comparable to a classic transportation problem. It involves a constrained version of the well-known Traveling Salesman Problem: namely, given a set of random locations, what is the minimum distance the salesman must travel to visit all points? Of course, there is no known closed form solution to this classical problem.

In this analysis, the constraints imposed by the buoy deployment problem are, in general, assumed to be:

(1) The deployment ship must return to the original deployment port.

(2) The number of buoys to be deployed is much greater than the number of buoys carried per trip.

*Cruise scheduling is defined as the sequence in which a deployment/maintenance ship visits given geographical points.

The first constraint can be relaxed, but that will not be done in this analysis. The second constraint is essentially axiomatic for this problem (if it is relaxed, the problem reverts to the classical one).

While it is true that an optimum solution to the deployment problem is difficult to achieve, it is possible to show by demonstration using specific simple models that one deployment strategy is better, equal to, or worse than another strategy. Because data buoy deployments are by no means totally random, it is also possible to look at certain easily manipulated, geometrically describable deployment patterns and analytically show relative preference for certain deployment schedule strategies. In short, in certain instances "common sense" buoy deployment schedule strategies can be augmented, guided, or confirmed.

B.2 An Example: Circular Buoy Deployment Patterns

As a first example of preferable buoy deployment strategies, consider the simple circular buoy deployment pattern shown in Fig. B-1.

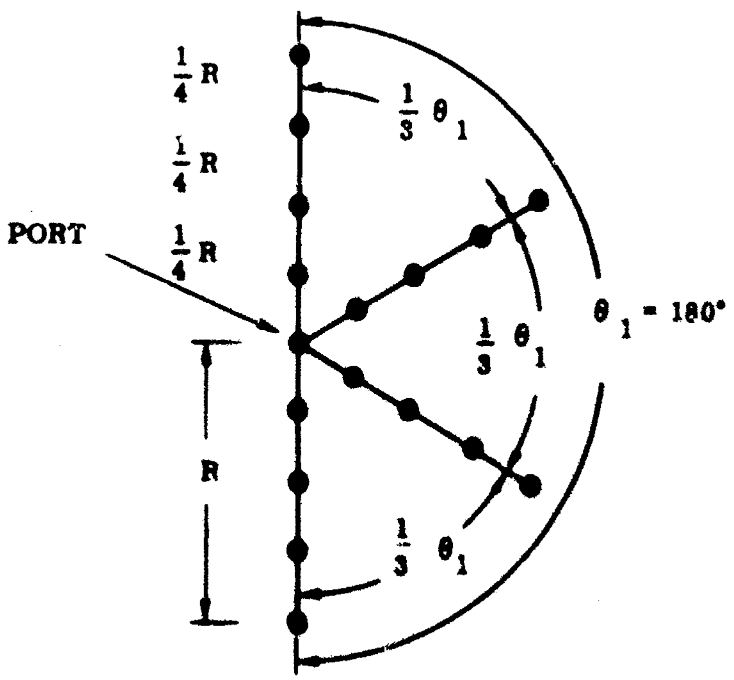


Fig. B-1. Buoys Uniformly Distributed

Assume the deployment ship carries 4 buoys per trip. Then two simple alternative deployment strategies are: *

(1) Make 4 round trip trips, going out each line of buoys and returning

(2) Make 4 trips, deploying 4 buoys on a circumferential pattern, at radius = R, 3/4R, 1/2R, and 1/4R.

In the first case, the total distance traveled is 8R. In the second case, the total distance traveled is $5R + 2.5\pi R$ (= 12.85 R). Therefore, it is clear that the first deployment strategy is to be preferred.

If the angle θ_1 is reduced, a crossover point can be found at which the distance traveled using the second scheme is equal to 8R. For still smaller values of θ_1, it is preferable to use the second deployment scheme, because the distance traveled is less than 8R. The value of θ_1 at which the two schemes result in equal distance traveled is found from:

$$5R + \frac{5}{2} \pi R \frac{\theta_1}{180} = 8R$$

or,

$$\theta_1 = (180) \frac{6}{5\pi}$$

$$= 68.8 \text{ deg}$$

This condition is shown in Fig. B-2.

B.3 Second Example: Rectangular Buoy Arrays

As a second example, consider the case where the buoys are all grouped together at a distance from the port that is large compared to the equal spacing between buoys. Assume for convenience that buoy spacing is uniform, as shown in Fig. B-3. Let Deployment Scheme 1 be that shown in Fig. B-4(a) and Deployment Scheme 2 be that shown in Fig. B-4(b).

*There are obviously other strategies in addition to these two.

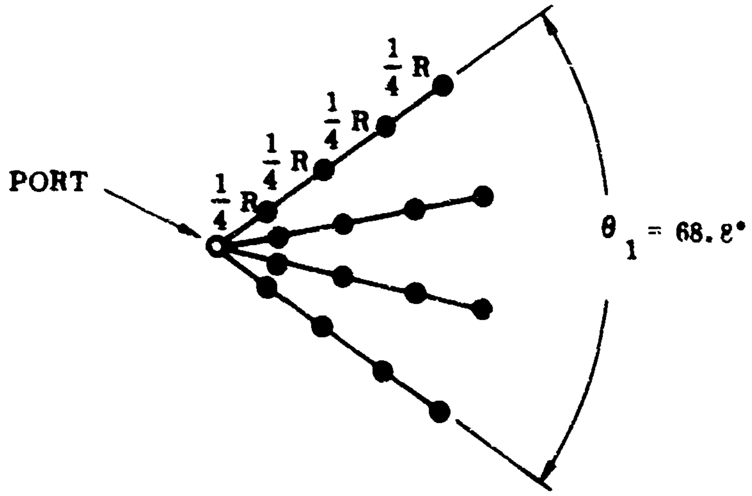


Fig. B-2. Deployment Strategy Crossover Configuration

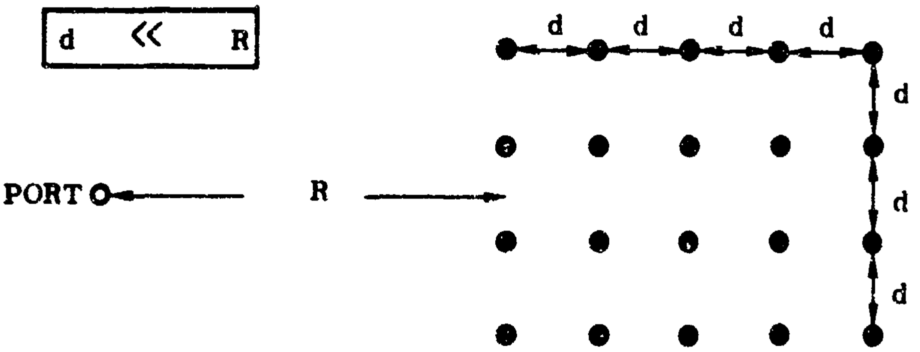
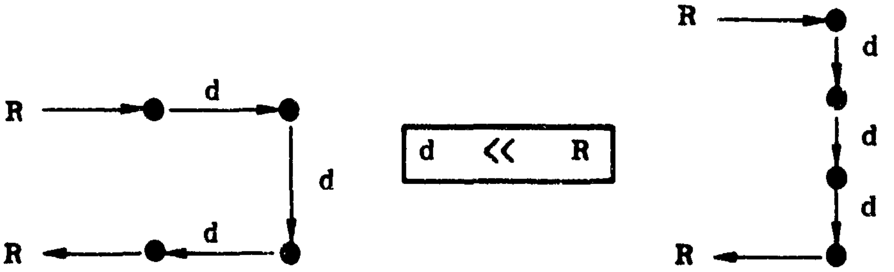


Fig. B-3. Buoys Remote From Port



(a) Scheme (1)

(b) Scheme (2)

Fig. B-4. Two Deployment Schemes

It is apparent that for Scheme 1 the distance traveled to implant 8 buoys with a 4-buoy capability ship is approximately 2 x (2R + 3d), while for Scheme 2 the distance would be (2R + 3d) + (2R + 5d). Obviously, Scheme 1 is preferred because a savings in distance of 2d can be achieved.

A comparable case might be the deployment of 16 buoys using an 8-buoy capacity ship, for the configuration shown in Fig. B-3. Using Scheme 1 requires approximately (2R + 7d) x 2 distance traveled. Scheme 2, modified as shown in Fig. B-5, requires (2R + 7d) + (2R + 11d). Again, Scheme 1 is preferred because of the saving of 4d distance, in this instance.

B.4 Third Example: North Atlantic Deployment

Based on the demonstration of preferred deployment strategies for simple deployment configurations, it is possible to extrapolate to more complex configurations comparable to those associated with NDBS deployments. The third example (Fig. B-6.) is a simple geometric approximation to a North Atlantic Modular Deployment Zone with approximately 30 to 40 buoys, with deployment from a centrally located U.S. port, such as Portsmouth, Va. The deployment field can be approximated by a 4 x 8 array of buoys with a uniform spacing of d. The port is taken to be on the horizontal line fourth from top. A buoy deployment vessel with a capacity of 8 buoys is directly applicable to this general problem, assuming there is no constraint on trip time.*

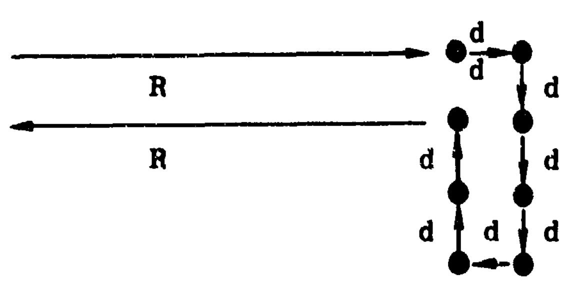


Fig. B-5. Scheme 2 Modified

*A trip time constraint can be overcome by reduction in time-to-plant and/or by increased ship speed, in some instances.

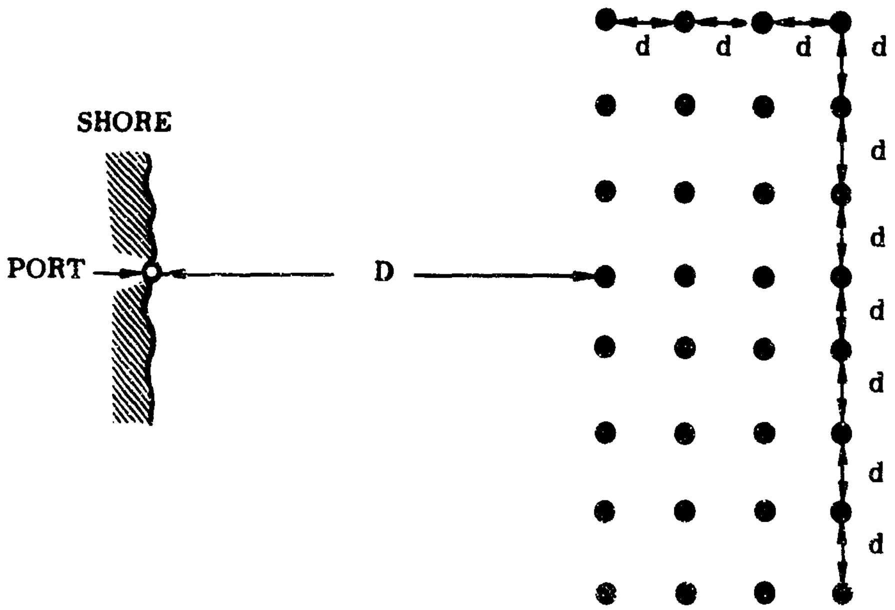


Fig. B-6. An Idealized North Atlantic Buoy Deployment

Three deployment schemes will be demonstrated, as shown in Fig. B-7. The total distances traveled are:

<u>Scheme 1</u>

Total deployment distance =

$$D + 2\sqrt{D^2 + d^2} + 2\sqrt{D^2 + 4d^2} + 2\sqrt{D^2 + 9d^2} + \sqrt{D^2 + 10d^2} + 28d.$$

<u>Scheme 2</u>

Total deployment distance =

$$\sqrt{D^2 + 9d^2} + \sqrt{D^2 + 16d^2} + \sqrt{(D + d)^2 + 9d^2} + \sqrt{(D + d)^2 + 16d^2}$$

$$+ \sqrt{(D + 2d)^2 + 9d^2} + \sqrt{(D + 2d) + 16d^2} + \sqrt{(D + 3d)^2 + 9d^2} + \sqrt{(D + 3d)^2 + 16d^2}$$

$$+ 28d$$

<u>Scheme 3</u>

Total deployment distance =

$$\sqrt{D^2 + 4d^2} + 2\sqrt{D^2 + 9d^2} + \sqrt{D^2 + 16d^2} + 14d$$

$$+ \sqrt{D^2 + d^2} + D + 7d + \sqrt{(D + 2d)^2 + d^2} + D + 9d$$

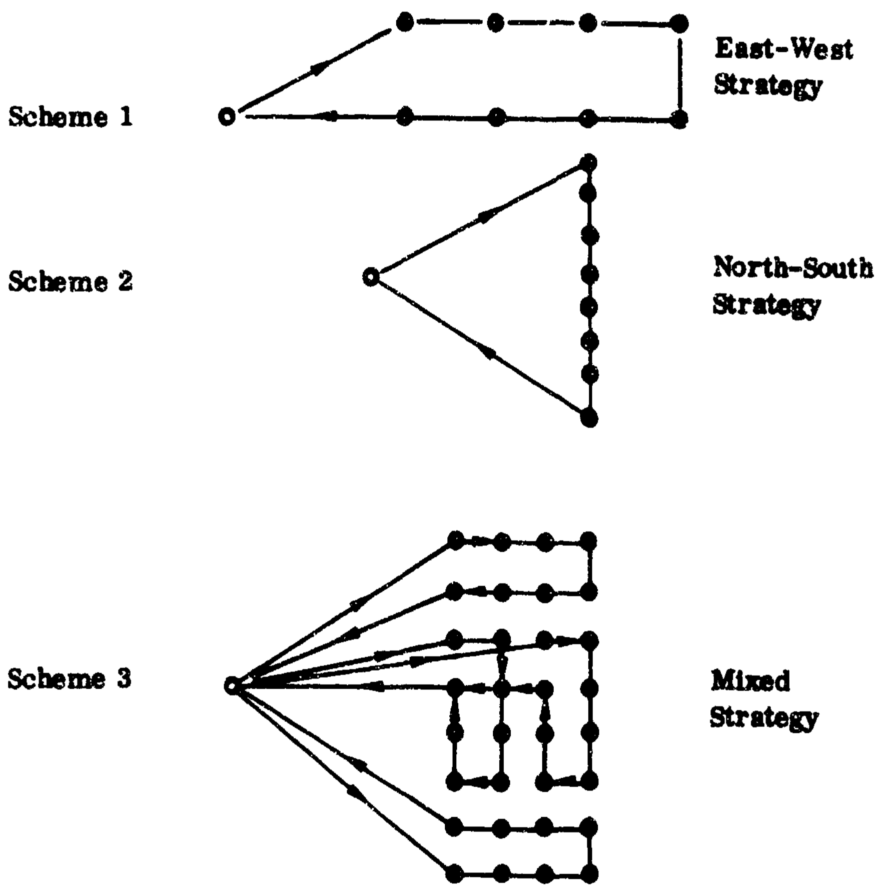


Fig. B-7. Three Deployment Schemes for the North Atlantic

By comparing non-equal terms from the Scheme 1 and Scheme 2 expressions, it is obvious that Scheme 1 is preferred:

Scheme 1		Scheme 2
D	$<$	$\sqrt{D^2 + 9d^2}$
$\sqrt{D^2 + d^2}$	$<$	$\sqrt{D^2 + 16d^2}$
$\sqrt{D^2 + d^2}$	$<$	$\sqrt{(D + d)^2 + 9d^2}$
$\sqrt{D^2 + 4d^2}$	$<$	$\sqrt{(D + d)^2 + 16d^2}$
$\sqrt{D^2 + 4d^2}$	$<$	$\sqrt{(D + 2d)^2 + 9d^2}$
$\sqrt{D^2 + 9d^2}$	$<$	$\sqrt{(D + 2d)^2 + 16d^2}$

Scheme 1		Scheme 2
$\sqrt{D^2 + 9d^2}$	$<$	$\sqrt{(D + 3d)^2 \; 9d^2}$
$\sqrt{D^2 + 16d^2}$	$<$	$\sqrt{(D + 3d)^2 + 16d^2}$

In fact, for the special case where $D = d$ (a very reasonable condition), it is quickly seen that for Scheme 1 the total distance traveled is 47.3d while for Scheme 2 the total distance traveled is 64.4d. Thus, Scheme 2 requires approximately 36 percent more travel than Scheme 1.

It is convenient to compare Scheme 3 with Scheme 1 in this same fashion. Scheme 3 requires a travel distance of 49.3d, or only 4 percent more travel than Scheme 1. Thus, while Scheme 1 is the preferred one, it is clear that Scheme 3 is a close competitor. In an actual case, where perfect geometric symmetry of spacing does not exist, conditions might be such that Scheme 3 becomes preferred.

For the special case where $D \ll d$ (which will be taken to the extreme condition of $D = 0$) the following relationships hold:

Scheme	Distance Traveled
1	42 d
2	59.6 d
3	45.2 d

Again, Scheme 1 is to be preferred, particularly over Scheme 2, but only marginally with respect to Scheme 3.

B.5 Fourth Example: A Port Within a Rectangular Buoy Array

Under certain conditions, buoy arrays may exist surrounding the service port (Honolulu, Hawaii, serving the Eastern North Pacific provides an excellent example). Based on guidance from previous examples, it is apparent that a deployment scheme approximating deployment along a radius is likely to provide the best strategy.

A typical example of buoys surrounding the service port is shown in Fig. B-8.

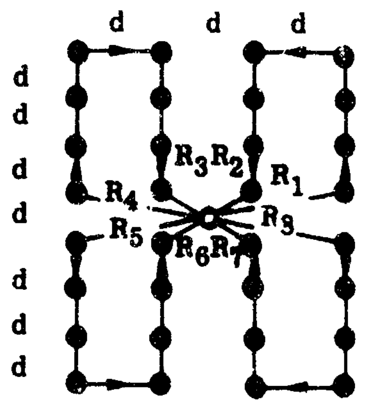


Fig. B-8. A Port Within a Rectangular Buoy Array

For the array shown, the shortest distance to be traveled in deploying the 32 buoys with a ship carrying 8 buoys per trip is:

$$\sum_{n=1}^{8} R_n + 28d$$

where R_n is the distance from port to first or last buoy deployed on a trip, as indicated in Fig. B-8.

If the buoy tender can carry 16 buoys/trip (or, if it can service 16 buoys after deployment), then the best strategy requires a travel distance of

$$R_2 + R_3 + R_6 + R_7 + 30d$$

The preference of these two strategies can be inferred from demonstrations in the previous examples, and need not be repeated here.

B.6 Summary

This analysis has attempted to establish -- by demonstration, not by rigorous general proof -- preferred strategies for deployment (and later maintenance) of data buoys. The general task involves finding a solution to a variation of the Traveling Salesman Problem. But the actual buoy deployment/maintenance task is a much constrained problem for which certain strategies are preferred and "good" (not necessarily optimum) solutions are often relatively obvious.

To simplify the analysis, several easily described geometric buoy deployment patterns have been analysed in some detail. In one instance (buoys on radial lines),

it has been shown that a crossover condition exists, making one deployment strategy preferable until crossover occurs, at which point the other strategy is the better. In the other examples considered, one strategy is always to be preferred, but in some instances the degreee of difference in distance traveled was minor, and in an actual application, deviations from the solution indicated for the "clean" geometric case might bring about a preference to use a mixed strategy.

The results given here have been used as guidance for the extensive TRC digital computer buoy deployment simulation. The TRC buoy deployment/maintenance model can be used to generate travel distances for any deployment scheme, hence, comparisons of deployment strategies specifically tailored to particular buoy and port locations can be easily achieved.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) UNITED STATES COAST GUARD	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

AN ANALYSIS OF CRUISE STRATEGIES AND COSTS FOR DEPLOYMENT OF NATIONAL DATA BUOY SYSTEMS.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

FINAL REPORT

5. AUTHOR(S) (First name, middle initial, last name)

THE TRAVELERS RESEARCH CENTER, INC.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
NOVEMBER 1968	175	FIVE
8a. CONTRACT OR GRANT NO. DOT-CG-82504-A	9a. ORIGINATOR'S REPORT NUMBER(S) 7493-337	
b. PROJECT NO.		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10. DISTRIBUTION STATEMENT

THIS REPORT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE: ITS DISTRIBUTION IS UNLIMITED.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	UNITED STATES COAST GUARD

13. ABSTRACT

The principal objective of this study is to develop cost information related to the physical deployment of automatic ocean data buoys at specified locations throughout the northern hemisphere deep oceans and coastal North American region (extending 400 nautical miles from shore). A bouy deployment/maintenance simulation and cost model was developed and computerized, accepting as imputs the geographical locations of data buoys and ports, costs, ranges of parameters to be investigated, ocean depth for each buoy location, and sequential schedules for deployment or maintenance of buoys. The simulation model computes great circle distance traveled for each cruise, cruise time as a function of ship speed and time-to-implant each buoy, and costs associated with each cruise. The results of computer analyses appropriate to the operation of National Data Buoy Systems are presented. Significant results include factors affecting the optimum maintenance ship design (a 12-buoy, 18-knot design was clearly superior), average number of buoys deployable per ship-year, comparison of use of three and eight deployment ports, average cost per buoy deployed, and similar factors useful in the initial design and development of National Data Buoy Systems. ( )